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ELEMENTARY STEAM ENGINEERING

BY

H. W. METCALFE

ENGINEER COMMANDER, ROYAL NAVY

WITH 144 DIAGRAMS

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PREFACE

THIS work in no wise pretends to be a text-book. Even the most elementary of existing engineering text-books naturally presuppose some knowledge of the laws of nature which rule the subject, being written for students whose education is generally fairly well advanced.

Very young students, such as the cadets at Osborne, in the large majority of cases know little or nothing at the commencement of the course either of physics or of mechanics, and their powers of observation have not yet developed, so that, without preparation, they would be utterly unable to grasp the meaning of such text-books.

By the time the student has thoroughly assimilated the contents of this book, he should be able to read a real text-book with understanding.

H. W. METCALFE
ENGINEER COMMANDER

ROYAL NAVAL COLLEGE, OSBORNE
August 3, 1904

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ELEMENTARY STEAM ENGINEERING

CHAPTER I

ENGINEERING SKETCHING

IN order to be able to understand the sketches made to illustrate engineering work, it is necessary first to thoroughly grasp the idea on which these sketches are made—what is meant by an "elevation," a "plan," and a "section," and how two parts of a piece of machinery which are touching each other are shown in a sketch in section; also what is meant by the dotted lines which one sees in engineering sketches, and what "shading" is.

In ordinary or "perspective" sketching, one draws an object exactly as one sees it from any one fixed point.

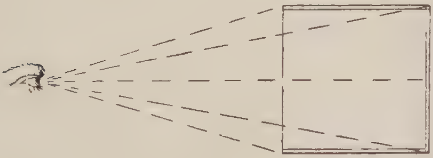


FIG. I

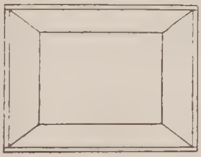


FIG. 2

Suppose we are looking at a square box, set on its side and with the lid removed, the eye being at the level of the middle of the box, as in Fig. 1.

Then if we drew what we saw, it would appear like Fig. 2.

In engineering sketching, however, we take no notice of perspective. We would be supposed to be looking straight at each part of the box as we drew it. We would draw the top of the box as seen from A in Fig. 3, and the bottom as seen from B, and in the same way for the sides.

Then our sketch would be as shown in Fig. 4.

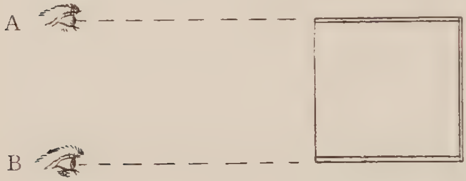


FIG. 3

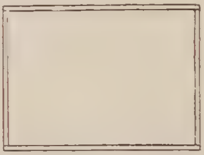


FIG. 4

An "elevation" of an object is a horizontal view—that is, from the side or end—as seen in this way.

So an engineering sketch of an ordinary wine bottle on a square stand would, in elevation, be as shown in Fig. 5.

A "section" is a view of the object as it would appear, from the engineering point of view, if it were cut fairly and truly in two, and the part between the eye and the plane of section removed. A section of a round object is always taken through the middle, so a "sectional elevation" of our bottle would be as shown in Fig. 5A. To show where the object is in section, that is, which are the cut faces one would see, these faces are "sectioned" as shown, by drawing a number of parallel straight lines diagonally across them. Where there are two pieces separate from but touching each other (the bottle and the stand in this case), these parallel straight lines are sloped in different ways in the two pieces to distinguish between them.

A "plan" is an engineering view of the object looking down from above. So the plan of our bottle on its stand would be as shown in Fig. 6. By comparing this plan with the elevation, we see that the smallest ring represents the inside of the neck, the next ring represents the outside edge of the neck, the next is the collar round the neck, and the outside ring of all is the outside of the bottle. Naturally the square outside the rings is the top of the square stand.

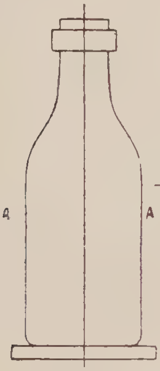


FIG. 5

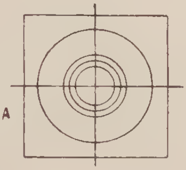


FIG. 6

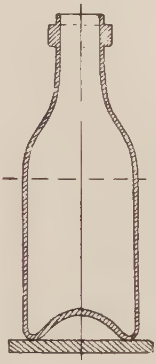


FIG. 5A

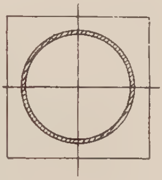


FIG. 6A

As a "sectional elevation" is a view of a section as seen horizontally, the object being cut through in the vertical plane, so a "sectional plan" is a view of a section cut horizontally through the object, and seen from above, that is, vertically. It is usual to draw a line across a plan at the point where the object is supposed to be cut in two to show the "sectional elevation," or across the elevation to show where the "sectional plan" is made.

The "sectional plan" of the bottle, then, at the line A—A in Fig. 5 would be as shown in Fig. 6A.

Very often, when the two sides of a thing are exactly alike, the elevation and the sectional elevation are combined in the one sketch, a "centre line" being drawn to show where the two parts of the sketch join.

The sketch would then be called an "elevation, half in section" or a "half-sectional elevation," and would be as shown in Fig. 7, the right-hand side being shown in section and the left in elevation.

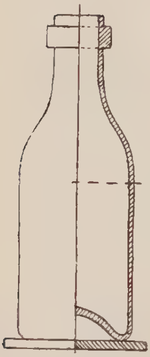


FIG. 7

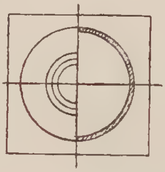


FIG. 8

Exactly the same is done in the case of a plan. The sketch would then be called a "plan, half in section" or a "half-sectional plan," and would be as shown in Fig. 8.

Now let us make our sketch a little more complicated. Let us suppose a cork in the neck of the bottle, and a tube through this cork, reaching nearly to the bottom of the bottle and open at both ends. Suppose the bottle still to be on its stand. Then the elevation would be as shown in Fig. 9, and the sectional elevation in Fig. 10.

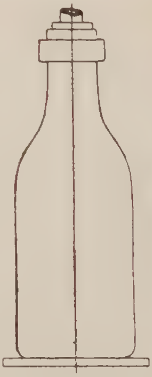


FIG. 9

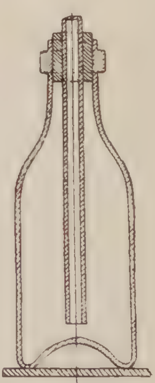


FIG. 10

Now in a case like this, where the sides of the object are thin and their thickness does not matter, as the "sectioning" would take time and be of little or no use, the sectioned parts would in a rough sketch like this be shown by one thick line instead of by two thin ones with the space between them "sectioned," as in

Fig. 10. The parts which are visible but not in section would be shown by thin lines, as in the case of the ends of the tube. The cork and the stand, being thick, would be "sectioned." Such a sectional elevation is shown in Fig. 11.

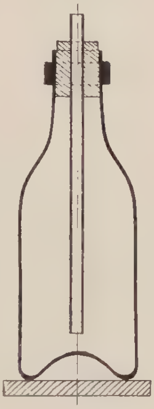
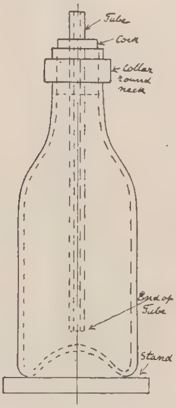


FIG. 11



[FIG. 12

Where it is necessary to show on a sketch what there is behind, then the parts hidden by what we actually see are shown by dotted lines. So in this case of the bottle, cork, tube, and stand, if it were necessary to show on the elevation where the tube ended and how far the cork extended, this would be done by means of dotted lines, as shown in Fig. 12. It will be noticed that the "arrows" are intended to show what particular sketch or part of a sketch is referred to. This is the usual plan in engineering sketching.

In a sketch where it is not required to show the whole of anything as being unnecessary for the proper understanding of the sketch, it is usual to "break off" that part where it becomes unnecessary, the "broken" part being sectioned. This is shown in Fig. 13, which represents a piece of thick round tube. A flat bar would be as shown in Fig. 14.

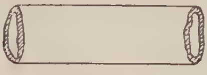
FIG. 13


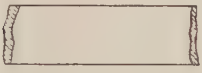
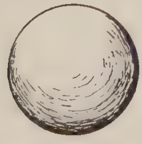
FIG. 14


FIG. 15

FIG. 16


When it is necessary to show that a thing is of round section—say a round ruler—it is usual to "shade" it as shown in Fig. 15, the "shading" being darker on the lower side than on the upper, and on the right-hand side than on the left, as the light is supposed to be coming from the upper left-hand corner of the object. The idea of this is that when we are writing or drawing with our right hand, we get the best light on our work if the light comes from this point, as our hand never gets "in the light," as it would do were the light coming from any other direction.

This idea is also shown in Fig. 16, which is a "shaded" sketch of a round ball.

THE USE OF SQUARED PAPER IN ROUGH SKETCHING

Throughout this book the sketches used for the illustration of the text are what are known as "rough" or "hand" sketches, being intended to convey the desired meaning in the quickest and easiest possible way.

They are called rough or hand sketches because the curves, rounded corners, small circles, section lines, and such like are put in by hand instead of with instruments, as being quicker. In "finished" drawings, such as are used to work from in the workshops, this rough-and-ready method would not be good enough, as it is necessary that every part of the drawing be accurately to scale, that is, if the length of any straight line which is to be, say, one inch in the finished article, be represented in the drawing by a given length, say one inch or half an inch or a quarter of an inch, then every other distance of one inch in the finished article must be represented by this same distance in the part of the drawing showing it.

For example, an elevation of our box in Fig. 4. Suppose the box to be 4 in. high and 8 in. wide. Then, in the finished drawing, the two horizontal straight lines representing the bottom of the box must be 4 in. apart if we decide to make the drawing "full size," or 2 in. apart if half size, or 1 in. apart if a quarter size, and so on. At the same time, the two vertical straight lines representing the sides of the box must be 8 in. apart in the first case, 4 in. in the second, and 2 in. in the third.

Again, if the scale decided on be, say, 1 in. equals 1 ft., then this view of our box will be represented by two horizontal straight lines, $\frac{4}{12}$ in. apart, joined at the ends by two vertical straight lines $\frac{8}{12}$ in. apart.

This would need accurate measurement, which takes a considerable time. In our rough-and-ready sketching, we desire to keep the proportions of the various parts fairly accurate, so as to convey a correct impression of the object; but we do not require absolute accuracy, and we wish to get through the work as rapidly as possible.

In addition to this general correctness of proportion, it is desirable, in order to make the sketch readily understandable, that horizontal lines in the object be represented by horizontal lines—or lines across the paper in our sketch—and vertical lines by vertical lines, or up and down the paper. This necessitates the use of a square, if the sketch be made on plain paper, as without a square it is very difficult to draw the lines correctly and parallel to each other. The use of the square also takes time.

In writing on a large sheet of plain paper, it is a somewhat difficult job to prevent our lines from straying out of the positions we would wish them to take.

The use of ruled paper, be the lines ever so faint, entirely gets over this difficulty, as we write along the lines and they keep themselves straight and parallel and square to the paper.

In our rough sketching, we will go a little further than this. Instead of only having lines *across* the paper, we have them *along* it as well, thus dividing the paper into small squares. The one set of lines will keep our horizontal lines correct, while the other will do the same for our vertical lines. Also, these lines will enable us to keep our proportions fairly correct without any trouble of measuring.

To further assist us in this matter, we have, say, every tenth line considerably thicker than the others, and we use these thicker lines as the centre lines (Figs. 7 and 8) from which to work in the making of the sketch.

When drawing a straight line, even if we already have a straight line on the paper, it is easier to use a ruler than to follow the line, if this line be of any considerable length, with our pen or pencil, so whenever convenient, we use a ruler. Also, the drawing by hand of a circle which we can recognise as a circle is very difficult, and even if we are fairly successful, takes much time if the circle be of any size. Yet with a pair of compasses, we can draw a perfect circle in a moment, so, whenever convenient and we have a pair handy, we use compasses. Otherwise we do the best we can by hand.

A sketch such as the majority of us would make, would, if on plain paper, be something like Fig. 17, while if done on squared paper, and using a ruler and a pair of compasses, it would be like Fig. 18—a much better result, and probably taking considerably less time.

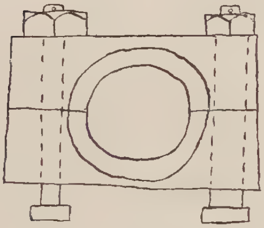


FIG. 17

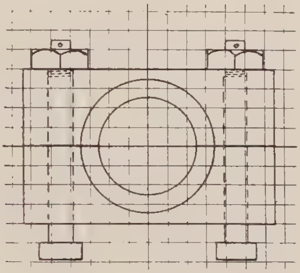


FIG. 18

CHAPTER II

NAVAL ENGINEERING

WHEN first Man desired to move across the face of the waters, he chose himself a log of wood whereon he sat, and by means of another piece of wood, used as a paddle, first on one side and then on the other, he propelled himself slowly along. As he grew more ambitious, he hollowed out his log by means of fire and so made himself a canoe, which he still propelled by means of his paddle.

Gradually his canoe became a boat, built up out of planks, as he could not always find suitable logs; but still he used his paddle wherewith to propel his boat.

Presently he thought to himself—" My one hand does most of the work, while my other merely serves to transmit this work, through my body, to the boat, and so force her along. Why not make the boat do her share of the work, and so take the strain off one of my hands?"

So he made the boat do her share of the work by letting his paddle—which now became an oar—press against a pin in the boat's side at the point where his second hand had grasped it. He found this easier work, but it was troublesome work changing his oar from side to side, in order to keep the boat straight, so he then used two oars, one on either side of the boat, when the boat went faster and the work tired him less. Still his ambition grew, and his small boat became a ship, with a number of oars on either side, each worked by one or more men. As the ship became larger there was not sufficient room to work enough oars all on the gunwale, and so the "Trireme," with its three tiers of oars, one above the other, followed.

All this time he had been using the force of the wind also to help him along, when it was blowing in a favourable direction. The leafy branch of a tree, which at first was good enough to catch the wind and help the boat along, soon gave place to a sail which was much better, being lighter and catching more wind. Gradually the sail was improved until, by its aid, the ship was enabled to travel, not only in the direction in which the wind was blowing, but also in other directions. When there was no wind the oars had to be used, but it was found that the number of men required to work these oars could not be carried in the ship, and so the oars had to be abandoned, except in very small vessels.

In large craft, when the wind failed—well, the ship stopped and waited until the wind got up again, when she proceeded with her voyage.

Then the steam engine was invented, and this seemed to be just the thing wanted to take the place of the men for propelling the ship when there was no wind, and so the sails were useless. Oars, however, were not suitable as the means of using the power of the steam engine to propel the ship, so the paddle wheel was invented. At first this took the form of two spars fixed across each other, with a paddle blade or "float" at the ends of the spars. One of these was mounted at each end of a "shaft" set across the ship at a little height above the water, so that the paddle floats dipped into the water as the "wheels" turned round, and so the ship was sent along by the floats forcing against the water, and became entirely independent of the wind.

Gradually more arms, or spokes, were added to the wheels, each carrying its paddle float; the ends of the arms were connected, and the paddle wheel became a true wheel, with a number of "floats" fixed round its rim.

This arrangement gave excellent results, and is still used in many steam ships, such as those running across the Channel, which do not have to make long voyages.

For ocean-going steamers having long voyages to make it was soon found that paddle wheels had many serious defects. Where they were used in ships to assist the sails in their work, when the ship "lay over" through the pressure of the wind on the sails, the paddle wheel on the "weather," or higher side, was lifted so high out of the water that the floats no longer caught it, while that on the "lee," or lower side, was so deeply sunken that the floats, instead of striking the water in such a way as to force the ship along, came down flat on the top of it, making a great splash, but doing very little useful driving. Also, at the commencement of a voyage the ship would be deep in the water, on account of the large amount of coal she carried to make steam for her engines during the voyage, and so her paddles were sunk too deeply in the water to give really good results.

By the time she neared the end of her voyage she would have burnt most of her coal, and so lightened herself that she would be floating too high in the water to enable her paddles to get a good grip. Beside these defects, the paddle wheels were easily damaged by striking floating wreckage. In a warship they were also liable to damage by the shot and shell of the enemy. The paddle shaft necessarily being at some height above the water, parts of the engines were also high up and unprotected. Also the large paddle boxes seriously interfered with the training of the guns. Consequently a better method of using the power of the steam engine to propel the ship than by means of the paddle wheels had to be devised.

This better method was found in the "screw propeller."

THE SCREW PROPELLER

When we see a ship moving through the water, forced along by some invisible means, we conclude that this is probably being done by a screw propeller, working silently and out of sight, hidden and protected by the water in which it works.

What is this screw propeller?

We all know what a wedge is—a piece of wood or iron with flat sides, quite thin at the one end and thick at the other, which we use for splitting logs of wood and innumerable other purposes. We first make a little crack in the log, and into this we put the thin end of the wedge, then with a hammer we drive the wedge in. What is the result?

The log is split in two. The force which would have been required to pull the two parts of the log asunder would have been enormous, but by means of the wedge we were able to split the log quite easily. Again, suppose we wish to lift a heavy block of stone, we put the thin end of the wedge under the edge of the stone and then drive it in, with the result that the stone is lifted up at the side under which the wedge is, even though the stone weighs a ton or more.

In Fig. 19 we place the thin end of the wedge under the edge A of the stone, and on driving it "home," this edge is lifted as shown in Fig. 20, the edge B still resting on the ground. Now suppose we put blocks of wood under the raised edge A, so as to support it at the height to which it has been lifted by the driving of the first wedge. Next, let us put the thin edge of another wedge under the edge B of the stone, and drive it home in its turn. The second side of the stone is thus raised to the height of the first, as shown in Fig. 21.

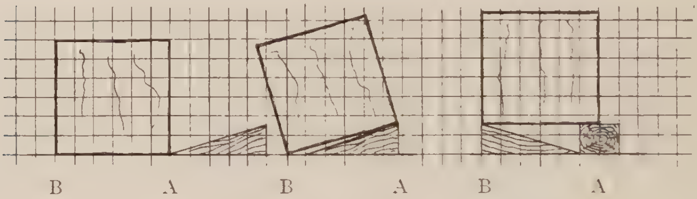


FIG. 19 FIG. 20 FIG. 21

It is evident that by the use of more blocks and more wedges we could raise our block of stone to any height we chose.

So much for the result; but what is this action of the wedge which enables us to get this result?

We see that by its use a comparatively small force (the blow of a hammer) can be made to lift a very great weight.

Why is this? Simply because the weight is lifted gradually. Walking uphill is hard work if the hill be steep, but if the slope of the road be gentle it is quite easy work, but we take longer in getting to the top as we go a much greater distance than if we went up the steep slope.

Where a carriage road zigzags up a steep hill, so that the horses can drag a heavy weight up, if we are in a hurry we take "short cuts," cutting off the corners of the zigzag, and we get to the top first. The horses could not possibly have dragged their load up these, as the hill would have been "too steep," though we, with only our own weight to take up, were able to manage it. Naturally, the amount of work done in getting from the bottom to the top was the same in each case—we only had to lift the weight through the same height. What can we conclude from this but that the steeper the slope the harder the work in getting up it, and that it is easier work getting to the top by walking up the gentle slope *because we take the work gradually?*

Let us try and prove this to ourselves.

On the edge of a table let us fix an upright, as shown in Fig. 22, and on the top of this upright fix a pulley, running as freely as possible. Let us take a block of lead, and by means of a string passing over this pulley connect it to another block of exactly the same weight.

Then this second weight will be unable to move the first; but on adding ever so little to it, we will see our first weight gradually hauled to the top of the upright, the second weight, of course, falling through exactly the same distance as the first has been hauled up.

Now let us mount our first block of lead on wheels, to represent a truck, so that it will run perfectly easily on its wheels, and instead of hauling it straight up as we did before, let us fix a board sloping from the table to the

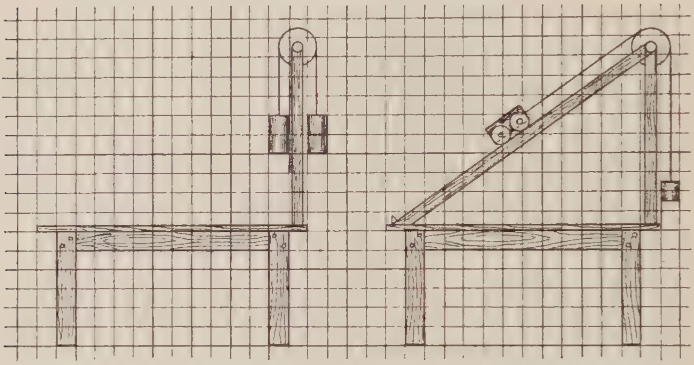


FIG. 22 FIG. 23

top of the upright, and let our truck run on this as in Fig. 23.

We find that a considerably smaller weight will now be sufficient to haul the truck from the level of the table to the top of the upright—but we see that this smaller weight has fallen through a considerably greater distance than the heavier one did before, though it has only hauled the truck up to exactly the same height. Of course this is the case, as the truck, instead of going straight up, has travelled up the slope, and the weight has fallen this same distance in hauling it up. This slope being the hypothenuse of a right-angled triangle, we know its length; for is not the square on the hypothenuse equal to the sum of the squares on the base and on the perpendicular? So we know how far the weight has fallen. We find that as the slope of the board becomes less and less steep, and so longer and longer, then the smaller and smaller does the weight required to haul the truck up the slope become; but as the weight decreases, so the distance through which it falls in hauling up the truck increases.

Of course there is a direct relation between the slope and the weight required to haul the truck up it.

If the truck travels twice as far in going up the slope as if hauled straight up, then the weight required will be one-half, and will travel twice as far. If three times, the weight will be one-third, and will fall three times as far. If four times, one-fourth, falling four times as far, and so on for any steepness of slope.

We see that this sloping board, which is called an "inclined plane," is just the same thing as our wedge, and so we naturally conclude that the "finer" the wedge (that is, the less its slope), the greater the weight it can be made to lift with the same exercise of power.

So much for the wedge.

Now a *screw propeller is merely a wedge, as is every other sort of screw.*

If we were to place a ship with her stern against a wall, and were to put the thin end of a wedge between the wall and her stern and drive it home, the wedge would force the ship away from the wall, that is, it would send her ahead.

This would not act for long, however, as we would very soon be at the end of our wedge, so we must arrange to make the wedge last longer.

Suppose we tie a string to the thick end of the wedge at the side, and let us tie the other end of the string firmly to the bottom of a round stake driven into the ground so that it can be freely twisted round and round but cannot be dragged sideways by pulling on the string.

Let the side of the wedge bear against the round stake, as shown in Fig. 24.

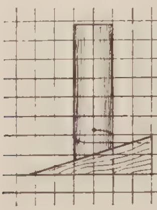


FIG. 24

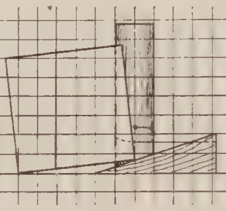


FIG. 25

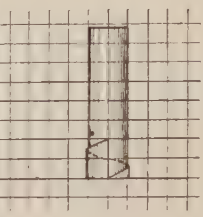


FIG. 26

If we twist the stake round and round, the string will be wound on to it, and the wedge will be pulled forward.

If we now place a weight, such as our block of stone in Figs. 19-21, with its edge resting on the wedge exactly opposite the centre of the stake, as in Fig 25, then when we twist the stake, and so force the wedge forward, naturally the weight will be lifted.

Now the only part of the wedge which was doing any work in lifting the weight was just that part exactly opposite the centre of the stake where the weight was actually touching. That being the case, it matters not in the least where the wedge goes beyond that point, nor where it comes from before it reaches that point, so long as it is there *just when it is wanted to do its work.*

That being the case, suppose we curve the wedge round so as to fit the round stake. The string will pull the wedge round when we turn the stake exactly as it did before when the wedge was straight, and each part will come into exactly the right place to do its work at the moment it is wanted.

Now why should we use the string at all? Why not fix the wedge straight on to the stake? The result would be the same, and would be as shown in Fig 26.

When we come to the end of the wedge we will be unable to lift the weight any higher, so let us use a block to support the weight at that height, and on the top of that block put another wedge. Of course the block will be curved round to fit the stake, as was the first wedge, and the second wedge will be similarly curved.

By continuing to twist the stake round, the weight will be lifted until the top of the second wedge is reached, the second wedge carrying on the work where the first one left off. This arrangement is shown in Figs. 27 and 28, Fig. 27 showing the two wedges and the block flattened out, and Fig. 28 showing them wound round the stake.

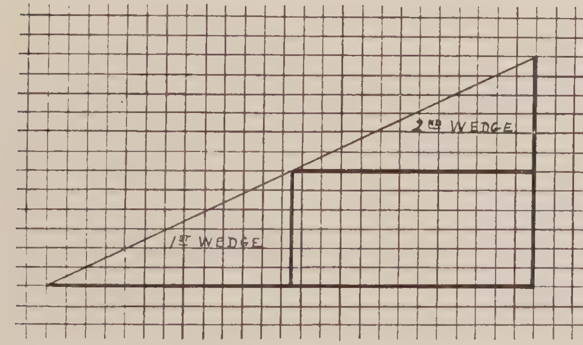


FIG. 27

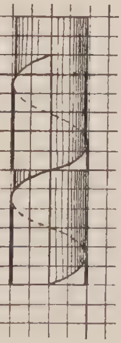


FIG. 28

From this we see that the two wedges and the block really form one big wedge, so let us consider this big wedge as being wound round the stake.

When we wish to make a screw, this is exactly what we do, but instead of the wedge we use a piece of paper cut in the shape of the wedge, and wind this round a "cylinder," say a ruler (the round stake was a cylinder), as shown in Fig. 29, where we see the edge of the paper forming a true "screw" round the ruler.

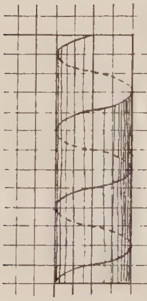


FIG. 29

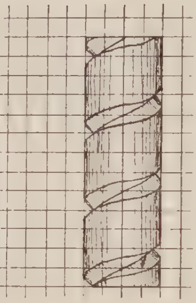


FIG. 30

If with a knife we now cut a deep groove in the ruler along the line where the edge of the paper is, we cut a "screw thread" on the ruler, as shown in Fig. 30.

If we make a hole in a piece of wood so that the ruler will just slide through it and be a perfect fit inside it, and then drive a nail into the wood so that its point projects into the hole just far enough to "engage" in the screw thread we have cut on the ruler, then this piece of wood becomes a "nut," and if we hold this nut so that it cannot turn, and then turn the ruler round and round, it will be forced along through the nut; or if we prevent the ruler from turning and turn the nut instead, then the nut will be forced along the ruler, the projecting point inside the nut travelling up the circularly arranged wedge or inclined plane forming the screw thread on the ruler.

Now it is clear that if we only have one nail point engaging with the screw thread on the ruler, and we use any considerable force in preventing the nut from moving along the ruler when we turn it, the nail point will bend or break off. So instead of one nail point only, we use a large number of points, all arranged to engage with the screw thread. Then we connect all these points until we have a complete spiral from end to end of the nut, which fits into the screw thread we have cut on the ruler.

We have now made a screw thread inside the nut as well as on the ruler, the thread on the ruler being called a "male" thread, and that in the nut a "female" thread.

Let us now fix our nut on to a board so that the ruler lies parallel with it, as shown in Fig. 31.

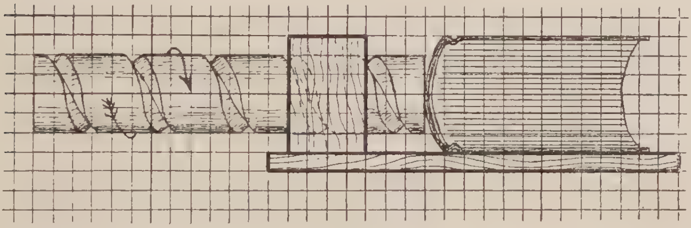


FIG. 31

If we put a book on the board, pressing against the end of the ruler, and then turn the ruler in the direction shown by the arrow, the book will be forced forward along the board.

The distance the book is forced forward by turning the screw through exactly one revolution is called the "pitch" of the screw. This distance can conveniently be measured on the screw itself, being the distance between the leading faces of the "threads" as measured straight along the screw.

This action is exactly what goes on when the screw propeller of a ship is made to revolve by the engines.

Of course, we have no solid nut to drive against, as we had in this case, but the water is made to serve as a nut.

The mass of the water forms the body of the nut, while the water which has filled up the screw thread on the "propeller" forms the screw thread of the nut.

As the propeller moves itself along through the water and so leaves the nut it had first used, new water is always flowing to it, or rather, it is working itself forward into new water to form a new nut, and so the action never stops, but becomes continuous.

The first screw propeller actually was a short length of an ordinary screw thread. It was made of metal, and as the material of which the nut was formed was water, which is yielding and much less strong than the metal of the propeller, the metal of the screw thread was cut away until only quite a thin wall remained between the grooves, so that the greatest possible quantity of water might be used to act upon the thread of the nut. This original form of screw propeller then was as shown in Fig. 32.

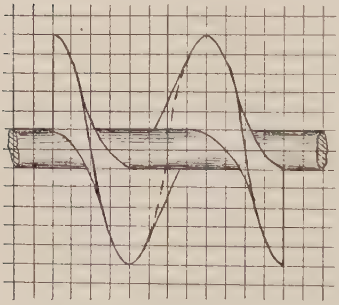


FIG. 32

It was fixed at the end of a "shaft" called the "propeller shaft," which passed through a hole in the stern of the ship and was made to revolve by the engines placed inside the ship. This hole was made such a good fit that there was no room for water to pass into the ship between the shaft and the sides of the hole; it also served to support the weight of the shaft and of the propeller outside. The general arrangement of the stern of the ship, with the propeller and shaft, is shown in Fig. 37.

It was very soon found that it was unnecessary to make the propeller so long, as only the very beginning of it did any useful work, the back part merely dragging through the water; so it was considerably shortened, thus also saving space. After a time, so that the propeller might take still less space, a piece of the screw thread was taken off the shaft and fixed on again exactly opposite another piece of the existing screw thread. This made what is called a "double-threaded screw," and the propeller became a "two-bladed propeller," and was as shown in Fig. 33. Then four blades were tried and the propeller became a "four-bladed propeller," as shown in Fig. 34.

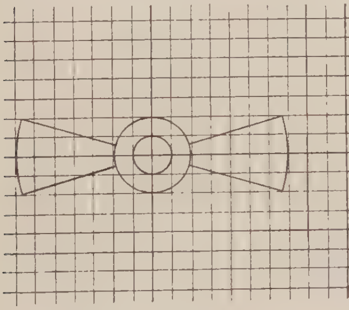


FIG. 33

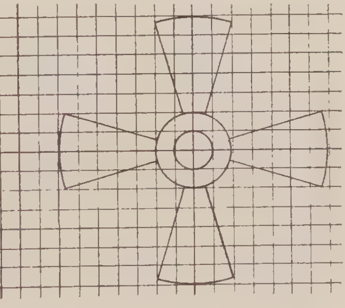


FIG. 34

The screw propeller of the present day is generally made with either three or four blades.

When climbing up a spiral staircase we notice that the steps are quite broad at the outside, but as they get nearer to the centre they become narrower and narrower, until they are of no use at all as stairs, and the work of climbing becomes very great. On the outside, the slope is comparatively gentle, whereas near the centre it becomes more and more steep until actually at the centre it is no slope at all, but goes straight up.

So with the screw propeller, which, if we come to think of it, is the same thing as the spiral staircase.

The middle and outer ends of the blades do all the useful work, while the parts nearest the shaft scarcely send the ship ahead at all, but take up power in uselessly churning the water. So the shaft where the blades were attached was made much larger, and the blades were fixed on to this large part, thus doing away with the useless part of the blades. Then this large part was made separate from the shaft, a hole was made through it for the shaft to pass through, a "key-way" was cut, half in the shaft and half in this part, which was called the "boss" of the propeller, and a "key" was fitted to prevent the propeller from turning on the shaft, so that the driving power of the engines should cause the propeller to revolve.

We now had an efficient propeller which, on being made to revolve in one direction, would push the ship forward, or if in the other direction, would pull her back, that is, which could be made to send her "ahead" or "astern."

Now came a point. If the propeller were sending the ship ahead, it would be trying to force itself along the shaft. To overcome this, the end of the shaft was made to taper toward its after-end, the boss was bored out to fit it, and the key-way was cut in the taper part, which was called the "cone" of the propeller shaft.

Naturally, the propeller could not now force itself along the shaft, but when the engines went astern it would pull off the cone. This was easily met by making the end of the shaft beyond the propeller boss parallel, cutting a screw thread on this parallel part, and screwing a nut on to it, bearing against the after-side of the boss.

Fig. 35 shows an elevation, and Fig. 36 a sectional elevation and cross-section of an ordinary two-bladed screw propeller fixed on its shaft in this way. In these sketches the parts are—

A Propeller shaft.
B Boss.
C Cone.
D Nut.
E Key.
F Blades.

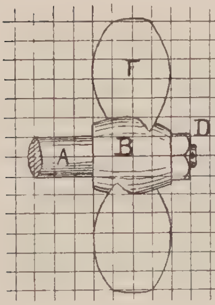


FIG. 35

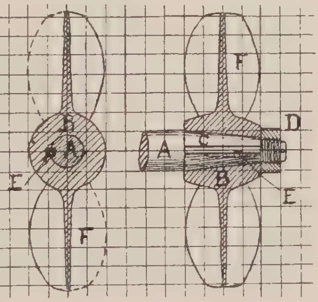


FIG. 36

As has been said before, propellers are now generally made with either three or four blades, as these numbers are found to give the best results, not only in actually driving the ship, but in causing the least possible amount of shaking when at work. This shaking, called "vibration," would not only be very uncomfortable for everyone on board, but would make accurate aiming with the guns impossible on account of the shaking of the sights.

THRUST

We have now found a thoroughly satisfactory propeller, which, on being caused to revolve by the engines inside the ship, forces her forward.

We have seen that the propeller is fixed on to a shaft passing through the stern-post of the ship, and that this shaft is made to revolve by the engines. The propeller is thus forcing against the shaft, and so sending the ship along. Now why is not the shaft forced forward in the ship when the propeller starts?

This forward force, which is called the "thrust" of the propeller, is taken by a "thrust block" firmly secured to the framework of the ship. Against this thrust block the shaft pushes, and so the power is transmitted to the hull of the ship, and she goes ahead.

In the first ship fitted with a screw propeller this thrust block was a very simple affair. On the shaft, just inside the ship, a large "collar" was made, and this "thrust collar" pushed against the thrust block, and so drove the ship ahead. This arrangement is shown in Fig. 37, which is a sectional elevation of the after-part of the ship.

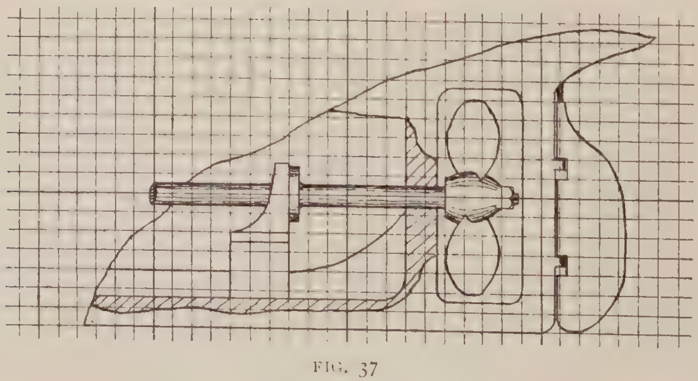


FIG. 37

Of course, it was at once found that when the engines went astern, to stop the ship or drive her astern, this thrust block and collar were of no use, so a second thrust block was fitted, against which the after-side of the thrust collar bore when going astern. Then the "ahead" and the "astern" thrust blocks were combined and made into one fitting.

Now a troublesome little point arose. On account of the necessity for keeping heavy weights away from the ends of the ship where there was nothing much to support them, and also because the bottom of the ship was too narrow near the stern for the engines to be conveniently arranged there, they had to be placed somewhere near the middle of the ship, which necessitated a long length of shafting between the thrust block in the stern of the ship and the engines in the middle. We know that metals expand when they are heated. If, then, this long piece of shafting became heated (as it will do at times), the expansion would be considerable, and the result would be that parts of the engines would be pushed out of position. This would be bad for the engines.

To get over this difficulty, the thrust block was removed from the stern of the ship, and was fixed just abaft the engines, so that there should be the least possible length of shafting between the thrust block and the engines to expand and cause trouble. The expansion of the shaft abaft the thrust block merely pushed the propeller a little further out, which did not matter.

Another point was scored by this bringing of the thrust block near the engines, namely, that it was much more accessible than when stowed away in the stern of the ship. As the thrust block requires constant attention, this was an important point.

The one large thrust collar was soon found to be a bad arrangement. When two metal surfaces are pressed hard against each other and one of them moves while the other stops still, "friction" results. Where there is friction, heat is generated, and the result is that the surfaces wear away more and more rapidly unless something can be used to reduce the friction and to carry away the heat as it is generated. To reduce the friction and to carry away the heat as it is generated, we "lubricate" the rubbing surfaces: that is, we run oil on to them in such a way that there will always be a thin film or layer of the oil between them, so that they shall never actually touch each other.

When we walk along the street, the friction between the soles of our boots and the pavement makes it possible for us to move along, as our boots "grip" the pavement.

If we tread on a piece of orange-peel, what is the result? We come down. Why is this? Because the orange-peel acts as a "lubricant" between our boot-sole and the ground, and so does away with the friction, our boot-sole losing its grip.

If we feel inclined to examine the place where we slipped, we find that there is a little of the orange-peel spread over the surface of the pavement for the whole of the distance through which the friction had been removed. *A thin film of lubricant* had been put between our boot-sole and the pavement.

Probably the result had been obtained long before the supply of "lubricant" was exhausted.

In machinery we arrange to use our lubricant over and over again for the sake of economy.

If we take a sharp pencil and put the point against our skin and then press hard on the pencil, we find that the point hurts ; but if we turn the pencil round and put the flat end instead of the point against the skin, then we can press much harder, but still not hurt, because the pressure, instead of being applied just at one point, is distributed over a considerable area.

That is just the case with the thrust blocks.

We must have considerable area over which to spread the pressure, else it would be so great as to force the lubricant from between the surfaces of the collar and the thrust ring, and then friction would result and the surfaces would soon wear away.

It was found that if the whole of the pressure were taken by one thrust collar, that collar had to be so large that it was impossible to lubricate all parts of the surface properly, and so there was too much friction and consequent wear of the parts.

The simplest way out of the difficulty was to have a number of smaller collars on the shaft instead of the one big one, so that each collar would take a part of the pressure, the thrust block of course being provided with a corresponding number of thrust rings for these to act against.

Each of these rings was now of such moderate size as to make satisfactory lubrication possible, and the "thrust area" was large enough to prevent the pressure on any part from being too intense. This arrangement is shown in Fig. 38.

So now we have a satisfactory propeller, and are able to use its power to force the ship forward or pull her back without risk of damage to any part of the machinery.

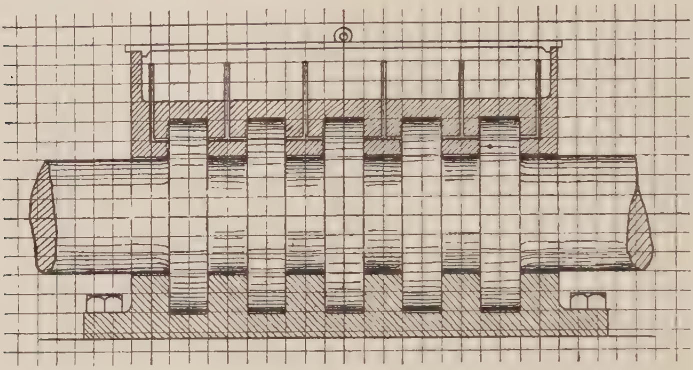


FIG. 38

PROPELLER SHAFTING

We have seen that the propeller outside the ship is made to revolve by the engines by means of a shaft called the propeller shaft, and so force the ship forward by pushing against the thrust block.

When we take a stick by two ends and, holding one end firmly, twist the other end round, that twist is transmitted along the stick to the hand holding the first end by a force called "torsion," and if we twist hard enough and the stick be not too strong, we will twist it off.

So with the propeller shaft. We must make it strong enough to withstand the torsion caused by the power of the engines driving against the resistance of the propeller, else it will twist off.

We have a long length of this shafting between the engines and the stern of the ship, and if it were all in one piece, and it were at any time necessary to remove it on account of repairs, one must first remove the engines so as to be able to pull it back out of the hole through which it passes in the stern of the ship.

Also it would be practically impossible to make such a long piece as would be required for a big ship all in one piece, and it could not well be got into place if it were made.

Consequently the propeller shaft is made in a number of pieces called "lengths," of convenient size, instead of all being in one piece. The aftermost piece, on to which the propeller is fixed, is called the "tail shaft," and the hole in the stern of the ship through which this tail shaft passes is called the "stern tube," there being a brass tube fitted inside the hole to carry the shaft.

These lengths of shafting are joined together by means of "couplings," called "flange couplings," and "coupling bolts" to form one complete shaft.

Fig. 39 shows a side elevation of the end of a length of shafting, the enlarged part through which the bolts pass being called the "flange." Two of these are brought together and fastened by means of a number of bolts, sometimes four, but more often six or eight, or even more in large shafts.

Figs. 40 and 41 show the complete flange coupling, Fig. 40 being the side, and Fig. 41 the end elevation.

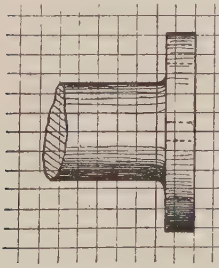


FIG. 39

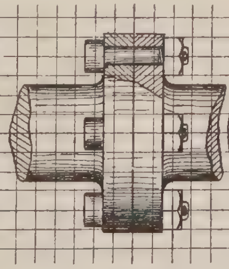


FIG. 40

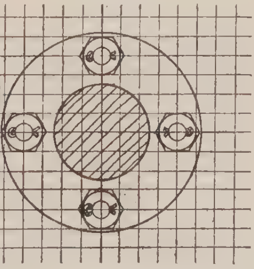


FIG. 41

The bolts not only hold the lengths of shaft together, but also serve to transmit the torsion from one length of shafting to the next, and so drive the propeller.

PROPELLER SHAFT BEARINGS OR PLUMMER BLOCKS

As all this shafting, with its couplings and bolts, is made of iron or steel, naturally it is heavy, and so would bend on account of its weight if it were supported only at its extreme ends. As the propeller shaft merely serves to transmit the power of the engines to the propeller, to make it revolve by means of the torsion of the shaft, and also to transmit the direct end-on thrust of the propeller, when at work, to the hull of the ship through the thrust block, it will be seen that there is no force at work which would cause the shaft to bend, except its own weight.

If we take a perfectly straight stick, put one end on the ground, and weigh down on the other end, we find that it will support a great weight without bending; but if we start to bend it, we find that it will no longer support the weight, but will bend more and more until it breaks. This is as shown in Figs. 42 and 43.

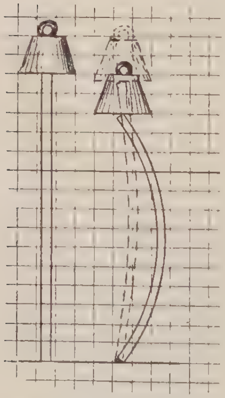


FIG. 42 FIG. 43

So with the propeller shaft.

If once we allow it to start bending on account of its weight, it will soon give way on account of the thrust.

So we must not allow it to start bending, and to this end we support it as necessary between its extreme ends by means of bearings called "propeller shaft bearings" or "plummer blocks," placed between the thrust block and the stern of the ship.

A beam, on which the shaft rests, fixed across the ship, would support its weight, but this would not be sufficient in practice.

When we were considering the thrust block we saw that it was necessary to distribute the pressure over a considerable area, so as to avoid wear on the thrust collars and rings. If a round shaft rests on a flat surface, it only touches that surface along a line, as shown in Fig. 44.

So if the shaft merely rested on a beam, the whole of the pressure due to the weight of the shaft would be taken by this line bearing along which it rested on the beam.

The area over which the pressure was distributed would then be so small that the pressure would be so intense as to force the lubricant from between the rubbing surfaces, and the friction would become so great as to rapidly wear away the beam, or the shaft, or both.

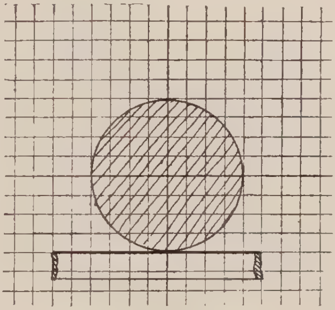


FIG. 44

Consequently the "bearing surface" has to be made larger, and instead of the shaft resting on the beam, it rests in a sort of trough fixed on the beam, which is placed lower down to make room for this trough or "bearing."

The shaft now, instead of resting on a surface represented by a line, rests on the bottom and sides of the trough, which encircles its lower half, and so the pressure is distributed over a considerable area, as shown in Figs. 45 and 46.

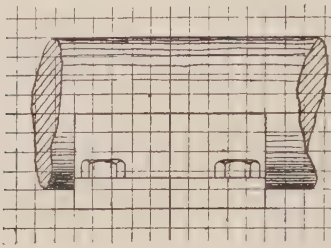


FIG. 45

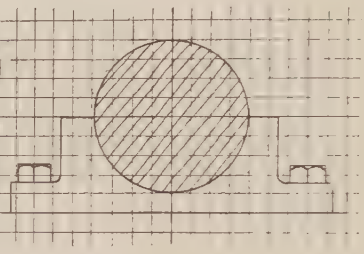


FIG. 46

As there is nothing to cause the shaft to bend upward or lift, it is unnecessary to have a bearing above the shaft as well; but it was found in practice that dirt and grit got between the shaft and the bearing, owing to there being no cover, and this caused friction, and so the surfaces were worn away. To prevent this a "cap" is fitted to the bearing, which not only serves to keep out the dirt, but also makes a convenient arrangement for supplying oil to lubricate the bearing, an "oil box" being made in the top of the cap with a small hole leading from it through the cap on to the shaft.

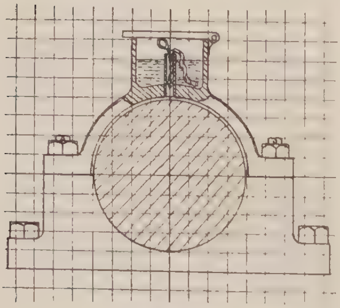


FIG. 47

The cap does not necessarily touch the shaft at all, as it has no real work to do, so generally a small space is left between them. Fig. 47 shows an end elevation of a complete propeller-shaft bearing or plummer block, the oil box being shown as forming part of the cap.

CHAPTER III

THE STEAM ENGINE

WE have now arranged for the satisfactory driving of the propeller by means of the propeller shaft, we have arranged for the transmission of the thrust of the propeller to the hull of the ship, and we have also arranged for the support of the propeller shaft throughout the whole of its length.

Arrangements have also been made for driving the ship astern.

The next thing we have to do is to drive the shaft by means of a steam engine.

So now we have to find out what a steam engine is.

First of all, what is steam? And what is the power in steam which we utilise for driving our shaft?

If we apply heat to water, the water boils away and becomes steam, as we see in an ordinary kettle. When we have applied enough heat, that is, when the kettle has been long enough on the fire, we find that all the water has boiled away and become steam. While there was water in the kettle we were able to keep the fire burning brightly, but yet did not hurt the kettle, as the water took away the heat from the bottom of the kettle as fast as the fire put it in.

But if we leave the kettle on the fire after all the water has been boiled away, we find that the bottom of the kettle becomes red-hot, and the kettle is ruined.

From this we conclude that a large amount of heat has been absorbed or taken up by the water in converting it into steam.

Again, if we take away the heat from the steam it "condenses," that is, it turns back into water.

If we hold a cold plate near the spout of a boiling kettle so that the steam strikes against it, we find that the plate quickly becomes wet, and water begins to drop from it; also the plate soon becomes hot.

The steam has been condensed by the cold plate robbing it of its heat.

If from the spout of the kettle, whose lid has been fixed down so that no steam can escape that way, we lead a pipe to a closed vessel kept cool by water running over it, we find that when all the water has been boiled out of the kettle we have exactly the same amount of water in the closed vessel as we had at first in the kettle, showing that the volume of the water is not in any way changed by its first having been turned into steam and then back again into water. The boiling of the water merely changed its state from a "liquid" to a "gas," just as when we heat a block of ice it turns into exactly the same weight of water, its "state" having been changed from a "solid" to a "liquid" merely by heat having been applied to it.

So we conclude that ice, water, and steam are all really the same thing, but at different temperatures.

The amount of steam given off by the boiling away of water is very great. If by boiling we convert 1 cubic inch of water into steam at the same pressure as the atmosphere, we get, as nearly as possible, 1 cubic foot of steam "at atmospheric pressure," that is, the volume is increased about 1,728 times by the change of state from water to steam.

Suppose we take a round tube (which we call a cylinder) exactly 1 square foot in sectional area (13·5 inches in diameter), with its bottom end closed, and into this cylinder we put exactly 1 cubic inch of water, then this water will cover the bottom of the cylinder to a depth of less than one-hundredth part of an inch—scarcely more than wet it all over, in fact.

Now let us place on the top of the water a "piston," that is, a thin round disc or stopper, which fits the cylinder so perfectly that it will slide up and down inside it quite freely, but yet leave no room between it and the sides of the cylinder for any steam or water to pass.

This piston will, of course, be more or less heavy, so we must arrange another weight to counterbalance it, so that it shall exercise no pressure on the surface of the water and will not in any way hinder the steam from pushing it up the cylinder.

This can be done in the way shown in Fig. 48, where a string attached to the

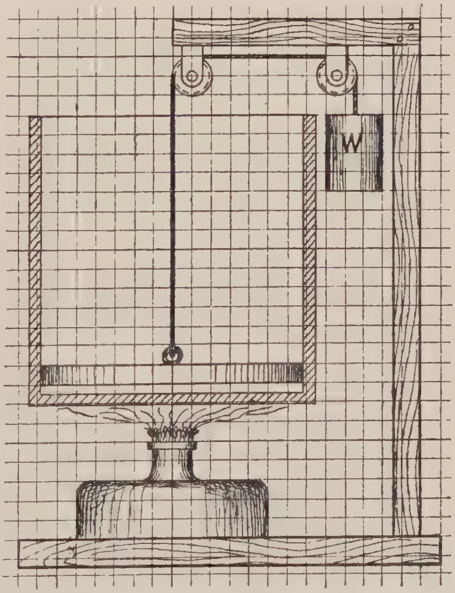


FIG. 48

piston passes over two pulleys on a support above the cylinder, and is then tied to a weight W exactly equal to the weight of the piston.

Now when we apply heat to the bottom of the cylinder the water boils, and as it boils the piston is pushed up the cylinder by the steam given off by the boiling water, until, when it has just all boiled away, we find that the piston has risen in the cylinder just 1 ft.; that is, the cubic inch of water has become 1 cubic foot of steam.

We have the pressure of the atmosphere acting downward on the top of the piston, and we know that this pressure is equal to about 15 lbs. on each square inch of its area.

As we have arranged that our piston shall exercise no downward pressure, the pressure of the steam below the piston must be the same as the atmospheric pressure above, and so we have our cubic foot of steam inside the cylinder at atmospheric pressure, that is, at 15 lbs. per square inch.

Now suppose, instead of 1 cubic inch of water, we put 2 cubic inches into the bottom of the cylinder, and suppose we stop the piston from rising beyond the foot in the cylinder. If we apply heat as before, the piston will rise until 1 cubic inch of the water has boiled away, when it will have risen the 1 ft. in the cylinder, as before; it will now be prevented from rising any further, but the water will still go on boiling until it has all turned to steam. Water, we know, is incompressible, but not so steam, which is the vapour of water, and so a "gas," and which we can compress into almost as small a space as we like if only we apply enough pressure, and the vessel in which it is contained be strong enough.

So we now have 2 cubic feet of steam squeezed into 1 cubic foot of space. When there was only 1 cubic foot of steam in the same space, we had a pressure of "one atmosphere" inside the space, so we naturally conclude that we now have double the pressure, namely, two atmospheres, or 15 lbs. above the atmospheric pressure. The "pressure gauge," the instrument used to measure pressures of liquids or gases, would now show "15 lbs. per square inch."

If we had allowed the piston to be moved by the steam as far as it would go, it would have risen 2 ft. in the cylinder, and if we had now forced it down until it was only 1 ft. from the bottom, we would have obtained the same result; so we conclude that if we

HALVE THE VOLUME, WE DOUBLE THE PRESSURE.

As the piston is 1 square foot in area, that is, 144 square inches, and the pressure acting on it to force it up is 15 lbs. on the square inch, the force with which the piston is now being pushed is 144 × 15 lbs. = 2,160 lbs., or very nearly a ton.

If, instead of 2 cubic inches of water, we had put 3 cubic inches into the cylinder, our pressure would have risen to three atmospheres, or 30 lbs. above atmospheric pressure, as we would have squeezed 3 cubic feet of steam into the 1 cubic foot of space.

The pressure gauge would now show "30 lbs.," and a force of nearly 2 tons would have been required to keep the piston from rising in the cylinder.

The piston would, if free, have risen 3 ft. in the cylinder, so we conclude that if we reduce the volume to one-third, we treble the pressure.

So 4 cubic inches of water, boiled in the cylinder, would give four atmospheres pressure, or 45 lbs., as shown by the pressure gauge, and the piston would have risen 4 ft. in the cylinder, and so on.

From this we conclude that

THE VOLUME VARIES INVERSELY AS THE PRESSURE.

That is—

$\frac{1}{2}$ the volume gives $\frac{2}{1}$, or double the pressure.
$\frac{1}{3}$ the volume gives $\frac{3}{1}$, or treble the pressure.
$\frac{1}{4}$ the volume gives $\frac{4}{1}$, or four times the pressure,
and so on.

This law, showing the relative volumes and pressures of gases, is called "Boyle's Law" from the name of its discoverer.

We have seen that by robbing steam of its heat, it is condensed, or turned back into water.

Now, in this experiment of turning water in the bottom of the cylinder into steam by the application of heat, unless we keep the whole of the cylinder and piston at a temperature equal to that of the steam (212 degrees by the Fahrenheit thermometer), heat will escape from the steam through the walls of the cylinder and condensation will take place, thus spoiling our experiment. As this temperature of 212 degrees is too high for comfort, we must try and demonstrate Boyle's law in a different way, using a gas which will not condense as does steam.

Air is the most convenient gas (or mixture of gases) for our purposes, as it behaves when under pressure almost exactly as does steam when kept at the temperature at which it is produced by the boiling of water at atmospheric pressure (namely, 212 degrees), and does not condense and so shrink at the ordinary temperatures such as are suitable for the carrying out of experiments.

If we take an ordinary bottle, such as a champagne or soda-water bottle, and securely cork it, with a tube passing through the cork into the bottle, and then by means of a force pump force through this tube into the bottle a volume of air exactly equal to that which was already in it, then we have two volumes of air squeezed into the space originally filled by the one volume when at atmospheric pressure.

The result will be exactly the same as when we boiled away the 2

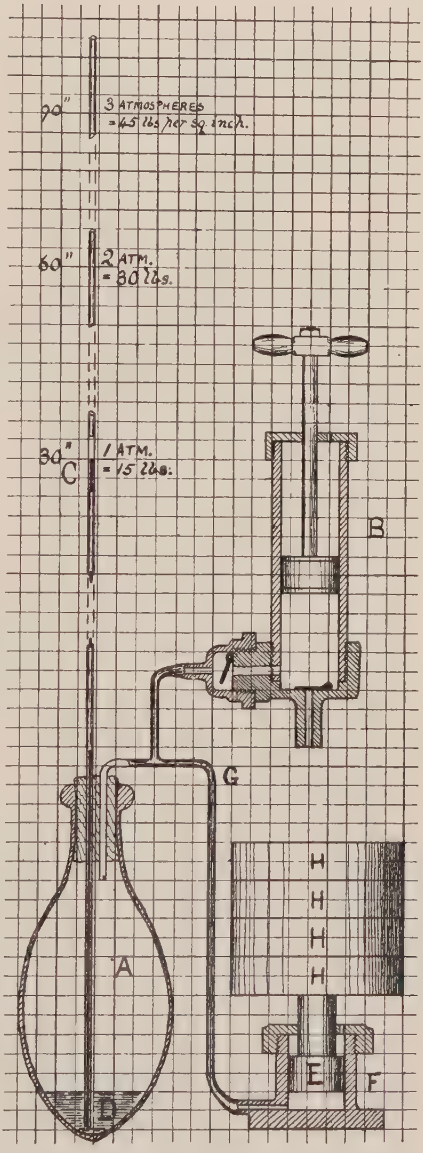


FIG. 49

cubic inches of water in the cylinder — that is, the pressure of the air inside the bottle will be doubled.

If we now force in yet another volume of air (equal to that put in before) by means of the force pump, there will then be three times the original amount of air in the bottle, and the pressure will be trebled, and so on.

We can conveniently show this pressure by seeing how far it is capable of forcing mercury up in a vertical tube.

The ordinary mercurial barometer we know merely consists of a tube sealed at its upper end, with its lower end, which is open, dipping into a vessel containing mercury, on the surface of which the pressure of the atmosphere is acting.

All the air being "exhausted" from the inside of the tube, there is no pressure at all acting on the surface of the mercury inside the tube. Consequently the mercury rises in the tube until the downward pressure of the mercury (due to its weight) is equal to the upward pressure of the atmosphere acting on the surface of the mercury outside the tube.

As this pressure of the atmosphere is not quite the same at all times, the height to which the mercury rises varies, and as the weather is largely dependent on the way in which this pressure is varying, the barometer is of great use in telling what sort of weather to expect.

A cubic inch of mercury weighs almost exactly half a pound, so, if we pour mercury to a depth of 1 in. into an open-ended tube 1 square inch in cross-sectional area, with a stopper in its lower end, the pressure tending to force this stopper out will be the weight of the cubic inch of mercury above it, namely, half a pound. For each additional inch we raise the level of the mercury in the tube, the pressure on the stopper is increased by half a pound.

In the barometer the mercury rises to a height of 30 in., and so we see that the pressure of the atmosphere which counterbalances the pressure due to the weight of this column of mercury is $\frac{30}{2} = 15$ lbs. on the square inch.

In measuring the pressure of the air in our bottle, we arrange a long glass tube, open at both ends, passing through the cork, and reaching very nearly to the bottom of the bottle, into which we put some mercury.

Before we start to pump in the extra air, the pressure on the surface of the mercury in the bottle is atmospheric pressure, as also is that on the surface of the mercury in the tube, so the level is the same in the bottle and in the tube. When, however, we pump in the second volume of air to the bottle and the pressure is thereby doubled, we have 30 lbs. pressure acting on each square inch of the surface of the mercury in the bottle, but still only the one atmosphere, or 15 lbs. on the surface of that in the tube. Naturally the mercury rises in the tube until the 15 lbs. atmospheric pressure and the pressure due to the height of the column of mercury are together equal to the 30 lbs. pressure in the bottle, when it will have reached a height of 30 in. above the level of the mercury in the bottle, corresponding to the extra 15 lbs. required to balance the pressure of the compressed air in the bottle.

On forcing another equal volume of air into the bottle, making three volumes compressed into the space originally occupied by one, the pressure is trebled, thus becoming 45 lbs. per square inch, and the mercury rises in the tube another 30 in., so that the pressure of 30 lbs., due to this 60-in. column of mercury, together with the 15 lbs. atmospheric pressure, counterbalance the 45 lbs. pressure in the bottle.

Similarly, when we pump in a fourth volume of air, the pressure is quadrupled, becoming

$$15 \times 4 \text{ lbs.} = 60 \text{ lbs. per square inch,}$$

and the mercury rises to 90 in. in the tube, exercising a pressure of 45 lbs.

If, instead of forcing additional quantities of air into the bottle, we force water in instead, the air in the bottle is compressed into less space, the water being incompressible, and so the pressure rises as the volume of the air is decreased.

Suppose the bottle to contain one quart and to be full of air at atmospheric pressure, if we force in half a quart (one pint) of water the space left for the air will be one pint, that is, the quart of air will have been compressed into half of its original volume, the pressure is doubled, and consequently the mercury rises to 30 in. in the tube. If now we force half a pint more water into the bottle, this space of one pint, in which the air is contained at two atmospheres pressure, will again be reduced to one-half its size, and the pressure of the air will again be doubled, thus becoming equal to four atmospheres, or 60 lbs. per square inch, and the mercury will rise to 90 in. in the tube. So by forcing in a known quantity of water we reduce the volume of the air by a known amount, and consequently can calculate its pressure.

We can also prove these pressures in a very simple manner by the use of actual weights.

If a piston of half a square inch in area (·8 in. in diameter), fitting perfectly in a short cylinder, be arranged so that the pressure of the air in the bottle shall act on its under side, by connecting the bottom of the cylinder to the bottle by means of a tube, then a pressure of 15 lbs. per square inch in the bottle, acting on the half square inch of the piston, will exert a force of 7½ lbs. on the piston-rod. If we place a 7½-lbs. weight on the top of the piston when the pressure in the bottle has been doubled, we find that it just balances the pressure underneath the piston, which now can be moved up and down in the cylinder by the very slightest exercise of force, thus clearly proving the original pressure of the atmosphere to have been 15 lbs. per square inch. So, again, if we treble the pressure in the bottle, the force tending to push the piston up will be two atmospheres, which, acting on the half square inch area of the piston, will require a weight of 15 lbs. to balance it.

The whole arrangement of this apparatus is shown in Fig. 49, where A is the bottle, B the force pump, C the mercury tube, D the mercury in the bottle, E the piston, working in the cylinder F, which is connected to the bottle by the pipe G, and HH are the weights acting on the top of the piston.

We saw, when considering the pressure exerted by the steam on our piston of 1 square foot in area, that a pressure of only 15 lbs. per square inch in the cylinder gave us the enormous force of nearly a ton on the piston, and similarly that 30 lbs. pressure gave us a force of two tons, and so on.

It follows clearly, from the points we have been considering, that if we have a volume of compressed air or steam at a pressure of, say, 60 lbs. per square inch, and allow it to expand to double that volume, we will still have a pressure of 30 lbs. per square inch; if, again, we allow it to expand to double that volume, the pressure will still be 15 lbs., and so on, the pressure decreasing as the volume increases until atmospheric pressure is reached. For the sake of illustration, let us look at the pressures and corresponding forces acting on a piston of 1 square foot in area, similar to the one we have been considering, working in a long cylinder, and let us suppose that there be 1 cubic foot of steam in the cylinder, at a pressure of 150 lbs. per square inch, or ten atmospheres, acting on the piston, then the pressures and consequent forces acting on the piston as it travels along the cylinder will be as shown in the diagram, Fig. 50.

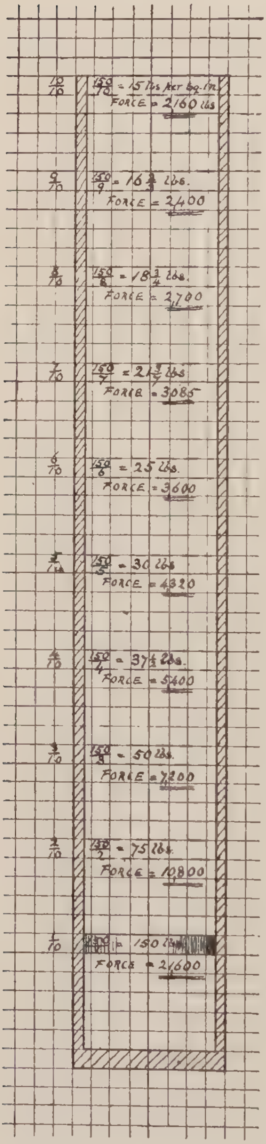


FIG. 50

This gives us some idea of the tremendous power which can be obtained by merely boiling water in a closed vessel, and this is the power which we use in the steam engine.

The point now comes—how to make use of this power.

We use a closed vessel, under which we light a fire, and which we call a "boiler," to make a supply of steam at any pressure we like, and we lead this steam, by means of a pipe called a "steam pipe," to the engine, where the power contained in the steam is turned into useful work in turning the propeller, and so forcing the ship along.

As the water in the boiler is turned into steam by the heat from the fire, and that steam is taken away through the steam pipe and used in the engine, naturally all the water which was first put into the boiler would soon be used up and the supply of steam would cease; so, as the water is used out of the boiler, in the form of steam, we must supply more. This is done by a pump called a "feed pump," which forces the water into the boiler against the pressure of the steam. This feed pump is either worked by the engine actually using the steam, or else by a small separate steam engine, the boiler supplying the steam to drive it. So we get a constant supply of steam.

Now let us take our cylinder and piston, which may be of any size necessary for the power required, but instead of counterbalancing the weight of the piston, let us put a heavy weight on the top of it.

From the boiler let us lead a steam pipe to the bottom of the cylinder, with a "cock" like an ordinary water tap in it, which we can open or close as we like; from the other side of the bottom of the cylinder let us lead another pipe, called the "exhaust" or "eduction" pipe, also "controlled" by a cock, and opening to the atmosphere. We will call the first of these (S in Fig. 51) the "steam cock," and the second (X in Fig. 51) the "exhaust cock."

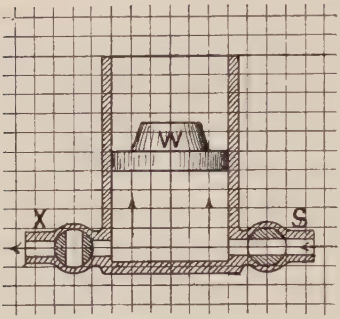


FIG. 51

If the piston be at the bottom of the cylinder and we close the exhaust and open the steam cock, the steam will rush into the cylinder, the pressure inside which will become much greater than the pressure of the atmosphere acting on the top of the piston, and so the piston with its heavy weight will be forced up to the top of the cylinder.

If we now shut the "steam" and open the "exhaust," the steam inside the cylinder will rush out until the pressure falls to that of the atmosphere, and the piston will be forced down to the bottom of the cylinder by the weight, pushing the rest of the steam through the exhaust.

Our piston will now have made what is called a "double stroke," that is, one "up" and one "down" stroke.

So as to be able conveniently to use the power of the piston moving up and down in the cylinder, we firmly fix in the centre of the piston a round rod called the "piston-rod," and we make a round hole in the centre of the cylinder bottom, through which the piston-rod works without letting any steam escape.

So we are able to use our power outside the cylinder, as shown in Fig. 52.

The first steam engines, made on this principle, were used for working pumps for pumping water out of mines, and this piston-rod was continued on to form the pump rod.

This weighted piston was a poor sort of arrangement, as a heavy weight was being lifted up at each up stroke and being let down again on the down stroke.

Also the steam was only doing work on the up stroke.

So means were devised for doing without the weight, and for using the power of the steam on the down as well as on the up stroke.

The top end of the cylinder was closed by means of a "cylinder cover," and another pair of steam and exhaust pipes and cocks were fitted at the top end of the cylinder, precisely like those at the bottom end. The two steam pipes on the one side were connected to the same main steam pipe, and the two exhaust pipes on the other side were also connected, so that there was only one pipe leading away from the engine to the atmosphere outside.

Then the arrangement of the cylinder with its piston, piston-rod, cover, and steam and exhaust cocks and pipes became as shown in Fig. 53.

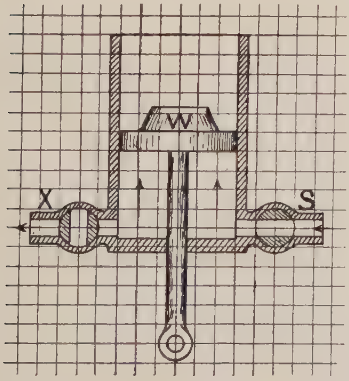


FIG. 52

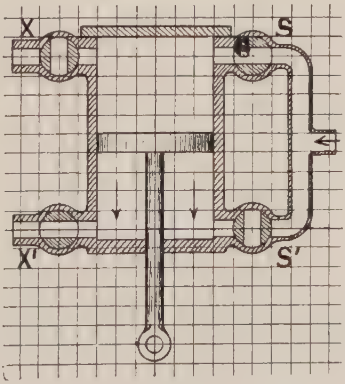


FIG. 53

We see from the diagram that by opening S′ and X and closing S and X′, the piston will be driven from the bottom to the top of the cylinder. Then by closing S′ and X and opening S and X′ it will be driven down again.

So by alternately opening and closing the cocks in the proper order, the piston can be made to work up and down and so work the pump, the power on the down stroke being the same as on the up.

This alternate opening and closing the steam and exhaust cocks was done by a boy, who was known as the "tappet boy."

It was very tedious work, so an ingenious tappet boy, who also happened to be lazy, thought that it would be a good plan to make the moving piston-rod do his work. By means of strings and pieces of wood he so arranged that when the piston nearly reached the end of its stroke, the end of the piston-rod caught one of the pieces of wood and dragged one cock open and another shut; at the other end of the stroke the piston-rod caught another piece of wood and dragged the first cock shut and the second one open, and so on.

He invented the self-acting steam engine, and went away to play marbles, but the engine went on working all the same.

Shrewd men were trying to improve the steam engine, and they very soon saw the value of the lazy tappet boy's invention, with the result that all steam engines were soon made self-acting. Many steam engines used for work on land are still worked on this principle, steel rods and blocks taking the place of the strings and pieces of wood.

The next point which arose was this—

There were two cocks to manage the supply of steam to the cylinder, and also two to manage the exhaust.

Why not make one thing do the work of the two steam cocks, and another that of the two exhausts?

One cock could not conveniently be made to do the work of either pair, so another plan was tried.

On one side of the cylinder a metal box called a "steam chest" was fixed, as shown at B in Fig. 54, running from end to end of the cylinder, capable of standing the full steam pressure, and covering the two holes at the ends of the cylinder where the steam cocks had been (these holes were now called "steam ports") in such a way that the inside of the cylinder was open to the inside of the steam chest at both ends. When steam was led into this steam chest by means of the steam pipe from the boiler, naturally it flowed into both ends of the cylinder at the same time. As it was necessary to allow the steam to enter into one end of the cylinder only at a time, a flat iron plate was fitted over the ports, inside the steam chest, working backward and forward on a flat surface prepared to receive it, on the side of the cylinder.

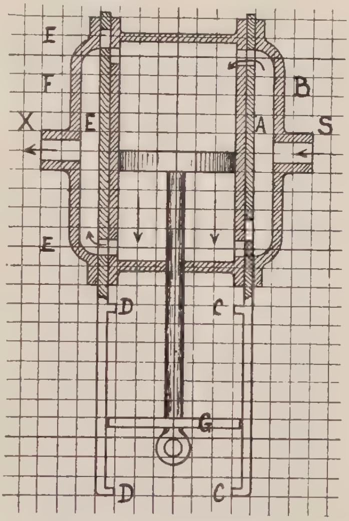


FIG. 54

This plate had two holes in it, each the size of a steam port, and at such a distance apart that when the plate was pushed back as far as it would go, the back hole in the plate would correspond with the back steam port, while the front steam port would be covered by the plate, and so the steam prevented from getting into the front end of the cylinder. On pulling the plate forward, the front hole in the plate would correspond with the front steam port, while the back port would be closed by the plate.

In order to be able to move this plate backward and forward, a rod called a "slide rod" was fixed to it, and passed through a hole in the front of the steam chest, in which it fitted steam-tight (like the piston-rod through the front end of the cylinder).

In this way steam could be admitted from the steam chest to either end of the cylinder, as required, by merely pulling the plate (which was called a "valve") backward and forward by means of the slide rod.

A similar arrangement was made for letting the steam out of the cylinder after it had done its work, first at one end and then at the other, as shown at F in Fig. 54; the only difference was, that in the exhaust valve the holes were further apart than in the steam valve, as will be seen at E in the sketch. On examining the sketch, we see that if both valves are pushed right back by the slide rods, the back steam and the front exhaust ports are opened, while the front steam and back exhaust are closed.

This was precisely what was done by our four cocks in Fig. 53, and so the piston will be forced by the pressure of the steam from the back to the front of the cylinder.

Similarly, when the piston reaches the front end of the cylinder, if the steam and exhaust valves are pulled forward by the slide rods, steam will be admitted to the front end of the cylinder, and the back exhaust opened to allow the used steam to escape. Consequently the piston will be forced back again, and we will have completed our " double stroke."

We see that in each case the valves had to be moved in the same direction as the piston was travelling just before it reached the end of its stroke, in order to make it go back again.

To make the piston-rod, as it moved backward and forward, work the two valves in order to make the engine self-acting, " tappets " C C on the steam side and D D on the exhaust side were fixed on the slide rods, and a " tappet bar " G was fixed on to the end of the piston-rod in such a way that it would catch the steam and exhaust tappets just before it reached the end of its stroke, and so push or pull the steam and exhaust valves A and E with it till they reached the ends of their strokes, when the steam and exhaust ports would be reversed, and the piston would commence to move back again. Just before it reached the end of this second stroke, the tappet bar caught the other pair of tappets, and dragged the valves back into their original positions; and so the piston started to make another stroke, and continued to move back and forth so long as the supply of steam was kept up.

The next point which arose in the evolution of our steam engine was this: These two long steam chests, reaching beyond the ends of the cylinder, were unwieldy and heavy, and also, as will be seen on examining the action of the steam valve in Fig. 54 while it was actually being moved from the one position to the other by the tappets, both steam ports were partly open to steam at the same time.

This was also the case with the exhaust valve; consequently steam rushed straight through from the steam chest to the exhaust at both ends of the cylinder during a certain portion of the stroke. Clearly this was a bad arrangement, there being a great waste of steam.

To get over this trouble, a different arrangement was tried. So far, the steam ports had merely been round holes through the sides of the cylinder, one at either end, as they had been when the cocks were used to control the "admission" and "cut-off" of the steam.

This necessitated the valve travelling a long way in order to completely shut the ports, which had to be of considerable size to allow the steam to get into the cylinder fast enough.

In order to make it possible to reduce this travel, the ports, instead of being made round, were made oblong in section, with the long way across the cylinder.

We can see that the same area of port for the passage of the steam could thus be obtained with a very much narrower port. For instance, a circle of 1·1 in. in diameter is as nearly as possible 1 square inch in area. A rectangle 4 in. long and $\frac{1}{4}$ in. wide is also a square inch in area. So a valve to shut off two such ports of the same area would have to travel less than a quarter as far in the case of the oblong port as in the case of the round one. Then, instead of the valve acting on these narrowed ports at the extreme ends of the cylinder, the ports were brought much nearer together, in a new and much shorter "cylinder face," as shown in Fig. 55, the part of the ports between the ends of the cylinder and this new cylinder face merely acting as steam pipes.

This enabled a much shorter steam chest and valve to be used. The steam valve itself, instead of having two holes through it, as it had before, was made simply of a flat plate (D in Fig. 55), which, when in its middle position, just covered both the steam ports.

When this valve was moved in one direction or other by the slide rod E, the port on the side toward which the valve was moving would remain closed, while the other port would be opened. Then when the valve was moved back again, the closed port would remain closed until the open one also was closed, when it would in turn be opened; so the two ports could never be open at the same time.

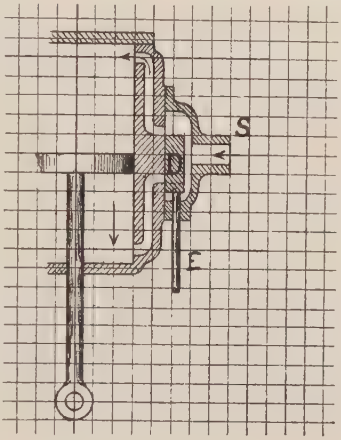


FIG. 55

In the case considered in Fig. 54, we see that the valve only moves just the width of the port in order to get the full opening to steam.

In this new case (Fig. 55), however, we see that it has to travel twice the width of the port, but as this width has been reduced to about a quarter of what it was in Fig. 53, by the use of the oblong instead of the round port, there is still a great gain as to the distance the valve has to travel in order to obtain the desired result; and the waste of steam due to both ports being open at the same time is avoided.

For the same reasons, a similar arrangement of valve and ports was needed to control the exhaust.

With this arrangement, then, the steam chests were reduced to a more convenient size, the valves were made much smaller, the "travel" of the valve was less, and both steam or exhaust ports were never open at the same time, so that steam was not wasted.

There were still, however, two valves to do the work of controlling the steam and the exhaust, and consequently two sets of tappets were still required. Also it was found that the pressure of the steam, when doing its work in the cylinder, acted on the face of the exhaust valve where it closed the exhaust port and forced the valve off the cylinder face, the pressure on the back of the valve being only that of the atmosphere, and so not sufficient to counterbalance the steam pressure on that part of its face on which it acted. The result was that steam leaked past the valve direct to the exhaust and was wasted.

Both of these objections were got over in a very simple way, which also greatly simplified matters and made the whole arrangement much lighter.

The steam valve was made to do the duty of the two, the steam pressure on its back more than counterbalancing the pressure acting on the small portion of its face covering the ports, thus ensuring its being in steam-tight contact with the cylinder face.

The way this was done was to make a hollow called the "exhaust cavity" in the face of the valve, leaving only two "bars" of the metal at the ends, each just wide enough to cover one of the ports, and so arranged that both ports should be closed at the same time, and by making a third port called the "exhaust port" in the cylinder face between the two steam ports, with a passage leading from it to the atmosphere.

As this exhaust port was always open to the exhaust cavity of the valve, naturally this cavity was always open to the atmosphere also.

Figs. 56, 57, and 58 show this new arrangement of the "slide valve," as it was now called.

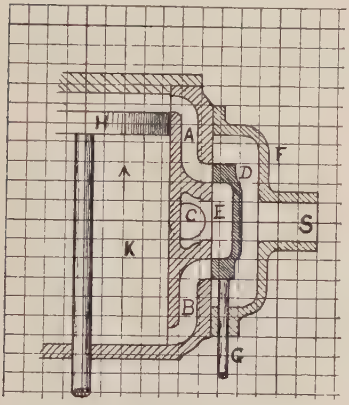


FIG. 56

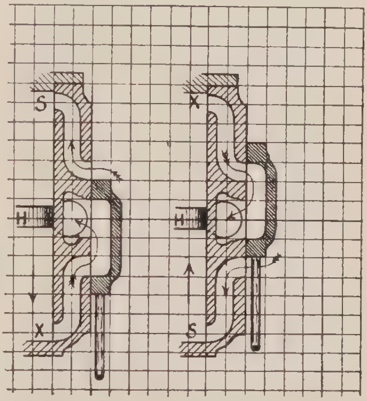


FIG. 57 FIG. 58

In these three figures the various parts are—

A and B	Steam ports.	F	Steam chest.
C	Exhaust port.	G	Slide rod.
D	Slide valve.	H	Piston.
E	Exhaust cavity.	K	Cylinder.

Fig. 56 shows the slide valve in its central position, the two steam ports being closed by the bars of the valve.

Let us study the action of this slide valve from the three sketches. First, let us pull it down by means of the slide rod into the position shown in Fig. 57, which is its extreme downward position. We see that the port A is uncovered, thus placing the top end of the cylinder in direct communication with the steam chest, and so by way of the steam pipe with the boiler.

At the same time we see that the lower bar of the slide valve has uncovered the lower port B and placed the bottom end of the cylinder in direct communication with the exhaust cavity of the valve. As this cavity, we have seen, is always open to the atmosphere by way of the exhaust port in the cylinder face, obviously the bottom end of the cylinder also is thus open to the atmosphere.

Consequently the piston, having full boiler pressure acting on the top and being free to the atmosphere beneath, will be forced down to the bottom of the cylinder, the exhaust steam passing out through the lower port to the atmosphere by way of the exhaust cavity of the valve and the exhaust port, as the piston comes down.

The piston having reached the end of its stroke, let us push the slide valve up into the position shown in Fig. 58, which is its extreme upward position. We then see that the top end of the cylinder has been opened to exhaust, and the bottom end to steam, and so the piston moves up again to the top of the cylinder.

Now we notice that when the piston reaches the top of its stroke the slide valve has to come *down* in order to make the piston return, and similarly, when it reaches the bottom of the stroke, it has to go *up*, which is directly opposite to the motion we had in the arrangement we considered in Fig. 54. So the system of tappets to work the valve in that case would not suit here.

We must reverse the action of the tappets, and this is very simply done by means of a pair of levers.

We know that if we place a plank, A B in Fig. 59, with its centre resting on a support C, on which the plank rocks, when we weigh down on the end A the end B goes up, and when we weigh down on B then A goes up, the direction of motion being reversed. This is exactly the motion we require to work our tappets, and so the slide valve.

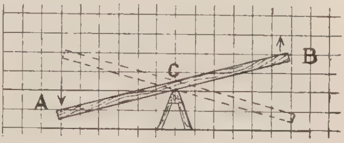


FIG. 59

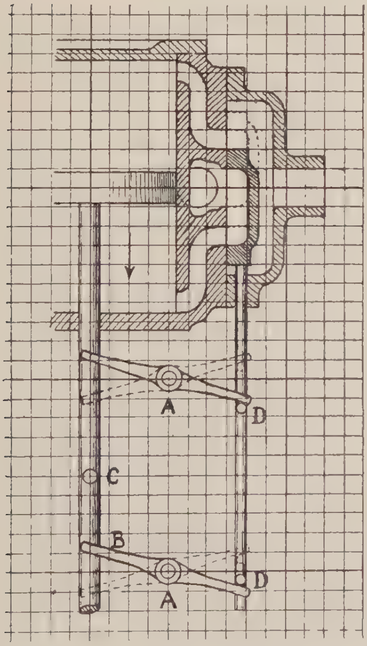


FIG. 60

So in Fig. 60 we arrange a pair of levers, pivoting about points A A, firmly fixed to the framework of the engine.

On the piston-rod we fix a spur or tappet C, which will strike the ends of the levers just before the piston reaches the ends of its stroke. The other ends of the levers catch spurs D D on the slide rod, and we get the desired result, the piston working up and down.

We have now satisfactorily arranged to utilise the enormous power of the steam in making our piston move up and down in the cylinder, and we can get at and use this power at the end of the piston-rod, moving up and down in a straight line.

This motion of the piston-rod in a straight line, back and forth, is called a "reciprocating motion."

We have seen that the screw propeller sends the ship forward by twisting itself through a nut, which it cuts for itself as it moves along in the water.

This round-and-round or "rotary" motion is imparted to it by means of the shafting, which is driven by the engines.

So far our engine has only a reciprocating or backward-and-forward motion in a straight line.

How is this reciprocating motion, caused by the action of the steam first on one side and then on the other of the piston, converted into rotary motion so that it may be used to turn the propeller?

This is done by means of an arrangement called a "crank."

THE CRANK

Take the case of an ordinary grindstone, a sewing machine, or any other machine where something carried on a spindle, passing through its centre and supported by bearings, is made to revolve by hand.

It would be impossible to turn the grindstone or work the sewing machine by simply twisting the spindle round with the hands or fingers—we would not have sufficient strength.

In each and every case of this sort the power is gained by means of a crank, even though it may not be called by that name.

The crank, if we come to think of it, is only a lever after all, using the centre of the spindle as a "fulcrum," and acting on the edge of the spindle, which becomes the "weight lifted," but instead of the "weight" being "lifted" through a small height, the edge of the spindle is forced round and round, the resistance of the grindstone or sewing machine to being turned, that is, the power required to drive it being the weight.

Fig. 61 shows this idea of the lever being used to turn a spindle or "shaft."

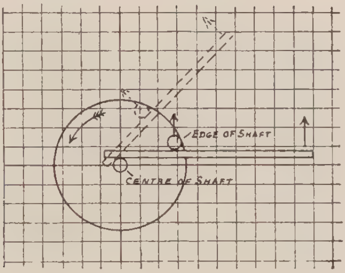


FIG. 61

In the case of the grindstone, supposing the spindle to be 1 in. in diameter, then, in twisting directly on to the spindle to revolve the stone, our fingers, or the parts of our hands actually touching the spindle to turn it, would, in making it revolve once, have supplied the power to do this in moving through a distance equal to the circumference of the 1 in. spindle, that, is, 3·1416 in.; but we could not have done it, the strain would have been too great.

So instead of trying to twist round on the spindle itself we use the handle, which is simply a conveniently shaped lever fitted on to the spindle.

Suppose the part we hold to be 1 ft. out from the centre of the spindle, that is, the actual lever which fits on to the spindle and stands out at right angles to it, to be 1 ft. long (the "crank arm" in Fig. 62), then we find that we can turn the grindstone easily.

Why? Because we have taken the strain required to turn the grindstone gradually.

Instead of moving only 3·1416 in., our hands have moved through a circle of 12 in. radius, that is, $2 \times 3{\cdot}1416 \times 12$ in. $= 75{\cdot}3984$ in. or over 6 ft., in doing the work which we tried to do in half as many inches, when twisting on the spindle itself, and failed.

That, we see, is simply a case of leverage.

To make the lever more convenient, its end is bent outward at right angles to it, and so parallel to the spindle, but at a distance of 1 ft. from its centre line.

The whole handle is a crank. The actual lever, fixed to the spindle or shaft and standing at right angles to it, is called the crank arm, the part we actually hold, and to which we apply the power, would in an engine be called the "crank pin," and the distance between the centre line of this part and the centre line of the shaft is called the "throw" of the crank. This distance is, of course, the radius of the circle through which our hands move in turning the grindstone. The various parts of the crank forming the grindstone handle are shown in Fig. 62.

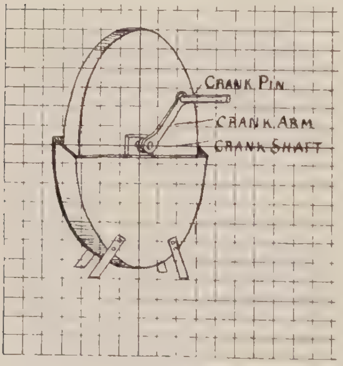


FIG. 62

From all this we infer that the longer the crank arm the greater the leverage, and so the power with which we can turn the stone, but also the greater the distance through which our hands have to move in doing the work.

Now in turning this grindstone by means of the handle or crank, we have alternately pushed and pulled on the handle or crank pin with our hands. If we keep our arms straight, but let them swing freely from the shoulder, we can still turn the grindstone quite comfortably, our body moving backward and forward as we turn it.

So our shoulder, at one end of the arm, moves backward and forward, while our hand, grasping the handle or crank pin moves round and round.

We have converted the backward-and-forward or reciprocating motion of our body into the round-and-round or "rotary" motion of the grindstone handle, and by means of the torsion of the shaft, have caused the stone to revolve.

As our arm was straight all the time, it was a "rod," that is, something with which we can both push and pull, and it connected the body (by its hinge at the shoulder) with its reciprocating motion, to the grindstone handle with its rotary motion, and so would in engineering be called a "connecting rod."

We notice that the arm being "hinged" to the body at the shoulder, allows the hand to move up and down as it pushes and pulls on the handle or crank pin as it moves round in a circle. Also we notice that this crank pin turns round and round in the hand as we work the grindstone.

Another point which we notice, and which is rather a troublesome one, especially when we are turning the grindstone with the arms straight, is that if the crank pin of the handle is straight away from us, so that the crank arm and our own are parallel, we are unable to start the stone revolving. If we push, the crank refuses to move, as it is already as far as it will go, and if we pull, we merely cause the grindstone spindle to press hard against the side of the bearing nearest to us, but in no wise tend to turn the stone. The forces are acting in a straight line, and as the bearing will not move there is no result.

The crank is on "dead centre," and push or pull as we may, it will not move. In order to start it, it is first necessary to turn the stone round a little, so that the crank pin shall not be in a straight line from the shoulder, beyond the crank shaft. Suppose we turn the stone so that the crank pin comes above this straight line, then if we pull, the top of the stone will come toward us ; if we turn it down and pull, the top of the stone will then go away from us. Naturally, at the other end of the stroke the same thing happens. So there are two dead centres, and in an engine with one crank care must be taken not to stop it on either dead centre, else there will be difficulty in starting again. When once the grindstone is started there is no further trouble, as the "momentum" or energy of the revolving stone will carry the crank past the dead centres ; but in an engine it is necessary to have a "fly wheel" to supply the necessary momentum, else the engine will stop.

In this case of the grindstone, the spindle or shaft ends at the lever or crank arm which is fixed to it, as it would prevent the arms from passing when turning the crank if it were continued any further, besides being unnecessary.

This form of crank is called an "overhung" crank, as the crank pin "overhangs" or projects beyond the end of the shaft, as shown in Fig. 63, and is very convenient for such work as the driving of a grindstone, where the power required is small, being supplied by

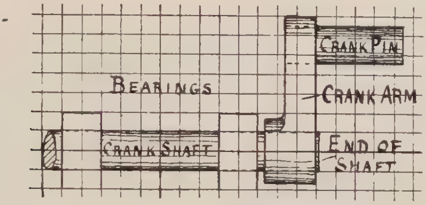


FIG. 63

one man. It is also often used in small auxiliary engines, where the power required is not great, and space has to be saved.

Where, however, the power is considerable, the overhung crank pin would bend, or the crank arm would twist under the strain, unless they were made exceedingly strong, as the crank pin is only supported at one end.

To make it stronger it is necessary to support it at its other end as well, and this is done by having another crank arm precisely like the first, at this end, with a

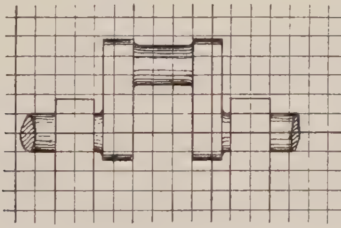


FIG. 64

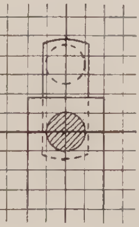


FIG. 65

piece of shaft attached to it, exactly in line with the first shaft, and also supported by a bearing, as shown in side elevation in Fig. 64 and in end elevation in Fig. 65.

The arrangement of the cylinder, with its piston and piston-rod, driving such a crank by means of a connecting-rod, is shown in side elevation, partly in section, in Fig. 66 and in an end elevation, partly in section, in Fig. 67, the valves for controlling the steam and exhaust being left out for the sake of simplicity, as also are the "columns" or supports, which bear the weight of the cylinder and take the strain due to the pressure of the steam on the piston, which is transmitted to the crank by means of the piston-rod and connecting-rod.

We see in Fig. 66 that the "crank shaft" (as the part of the shaft where the crank is fixed is called) is thus continued on a little beyond the second bearing, which is

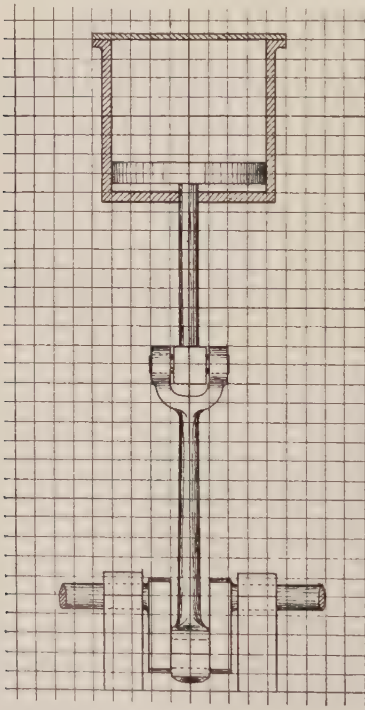


FIG. 66

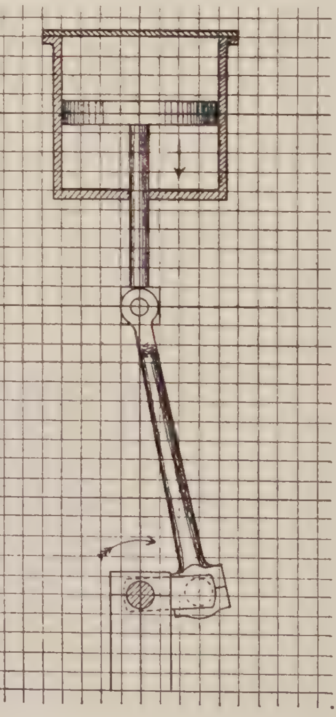


FIG. 67

called a "main bearing," as it not only supports the weight of the shaft, as do the plummer blocks or propeller-shaft bearings, but also takes the strain of the push and pull of the piston, due to the pressure of the steam acting on it, which we have seen is a much greater force than the mere weight of the crank shaft.

It is obvious that another cylinder can be arranged to act on another crank fixed on to this continuation of the crank shaft of the first engine, and a third and a fourth cylinder beyond that again, if desired, each acting on its own separate crank.

So by this arrangement of crank we can have as many cylinders as we like, all acting on the same crank shaft, and so all helping to turn the same propeller, the power of each cylinder being transmitted to the propeller shaft through the crank arms and crank pin of the engine next behind it.

Naturally the crank pin of the engine nearest the propeller will thus have a much greater strain on it than have those further away, as it not only has to stand the strain of its own engine, but it also has to transmit the power of the other engines to the propeller shaft, and so to the propeller.

It is necessary to make the crank pin large, so that the pressure on it shall not be too intense, for the same reason that the total area of the thrust collars is made large, namely, so that the lubricant shall not be squeezed out from between the rubbing surfaces. If in order to obtain the necessary area of crank pin, on account of lubrication, the pin were made long and of small diameter, it would not have sufficient "stiffness" and would bend under the heavy strain brought to bear on it.

If we support a rod on two blocks, as shown in Fig. 68, and place a heavy weight with an absolutely flat and rigid (that is, unyielding) bottom on the top of this rod, between the supports, then we see that the rod bends, and that instead of the bottom of the weight touching the rod all along, it only touches at the two ends; consequently the whole of the pressure due to the weight is taken just by these two points of contact, and so is intense.

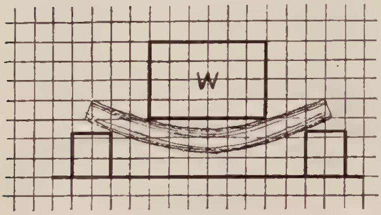


FIG. 68

This is exactly the case with the long thin crank pin. The bearing at the end of the connecting rod, through which the pressure of the steam on the piston is transmitted to the crank pin, is rigid, and so, if the crank pin bend even ever so little, this pressure will be transmitted to the crank pin by just the corners of the bearing; the pressure at these points will then be intense, the lubricant will be squeezed out, and these corners will rapidly wear away.

So the crank pin must not be allowed to bend under the pressure, and to prevent this it is made much larger in diameter than is actually necessary from the point of strength alone. The length, then, can be kept within reasonable limits, and yet the area over which the pressure is distributed remain large enough to prevent this trouble.

The diameter of the crank pin necessary from this point of view makes it amply strong enough to stand the strain of the other engines as well as its own, and so all the crank pins, whether there be two, three, or four, are usually made of the same size.

When considering the turning of the grindstone by means of the handle we saw that "the longer the crank arm the greater the leverage, and so the greater the power with which we can turn the stone."

We can see, on examining the sketch of the crank being driven by the connecting rod, piston-rod, and piston (Fig. 67), that the centre of the crank pin, in turning the crank shaft, goes as much above the shaft at the top of the stroke as it does below it on the bottom; so we see that the stroke of the piston is exactly double the "throw" of the crank, as the distance from the centre of the crank pin to the centre of the crank shaft is the throw of the crank. Consequently, if, in order to gain leverage and so power, we were to make the throw of the crank very great, the length of the cylinder would also be very great, but it could be of very small diameter and yet get the same power as a much larger piston acting on a much shorter crank.

For practical reasons such a long cylinder and piston-rod would be objectionable, so the crank is made of moderate throw, and so the cylinder and piston-rod also are of such moderate length as to be convenient, the cylinder, of course, being made of suitable diameter to obtain the power.

THE CROSS-HEAD

Again referring to the driving of the grindstone, where we said that the arm, acting as a connecting rod between the shoulder with its reciprocating motion, and the crank pin of the grindstone handle with its rotary motion, was hinged to the body at the shoulder to allow the hand to follow round in the path of the crank pin, the arm swinging up and down about this hinge.

In an engine this hinge is called the "cross-head," and the pin of the hinge is called the "cross-head pin."

The arrangement of this cross-head and cross-head pin is as follows—

The end, or "head," of the piston-rod C in Figs. 69 and 70 is enlarged, as shown at A, and through this enlarged part is fixed the cross-head pin B, with its centre line across that of the piston-rod, at right angles to it.

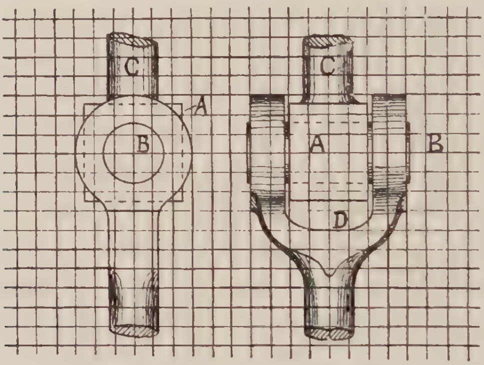


FIG. 69 FIG. 70

The upper end of the connecting rod is forked, as shown at D in Fig. 70, and in the sides of this fork are holes, through which the cross-head pin passes, thus joining the connecting rod to the piston-rod at the cross-head in such a way that if the piston-rod be moved up and down the connecting rod will be moved up and down with it, but will be free to swing from side to side, in Fig. 69, or backward and forward, in Fig. 70, as its lower end moves round with the crank pin. This arrangement takes the place of the shoulder joint in the case of the man turning the grindstone, the only difference being that, owing to the formation of the shoulder joint, the arm is free to move sideways as well as up and down, whereas in the case we have just considered the connecting rod is only able to swing in the one way. Naturally this does not matter, for, as in driving the grindstone, the arm only uses the shoulder joint to allow the one sort of motion, so this is all that is required in driving the crank.

CRANK-HEAD BEARINGS, OR "BRASSES"

We saw, when working the grindstone, that the handle, or crank pin, turned round and round in the hand, making one complete revolution every time we turned the grindstone.

So in the engine. The crank pin turns round and round, while the end of the connecting rod which is driving it does not. So the crank pin turns round and round in the end of the connecting rod.

If we simply enlarged the end of the connecting rod, and made a hole through it which would fit the crank pin, and allow it to revolve inside it, this would work all right in the case of an "overhung" crank pin, but in the complete crank which we have been considering it would be impossible to get it on to the crank pin on account of the two crank arms, one on either side of the crank pin.

To get over this the enlarged end of the connecting rod is cut in two, opposite the centre of the hole, as shown at B in Figs. 71 and 72, so that half of the hole is in the solid part of the connecting rod and half in the "cap," as the part which has been cut off is called.

By means of "crank-head bolts," C C in Figs. 71 and 72, these two parts are connected together in such a way that the two halves of the hole come exactly opposite each other to form one true round hole.

Fig. 71 shows an end elevation of a crank-head bearing, or "brasses," on the crank pin, the crank arm nearest us being removed, and Fig. 72 shows the front elevation of the complete crank, with the connecting rod attached. So, by removing the cap, the connecting rod may be swung into place, with the top half of the hole (that in the end of the connecting rod itself) fitting on to the top of the crank pin; then the cap is brought into place under the crank pin, the bolts are inserted and the nuts screwed hard up, and the end of the connecting rod becomes to all intents and purposes a solid block with a hole in it, encircling the crank pin, which fits the hole, but is free to revolve in it. The pressure of the steam on the piston can thus be brought to bear on the crank pin, and so make the crank shaft revolve.

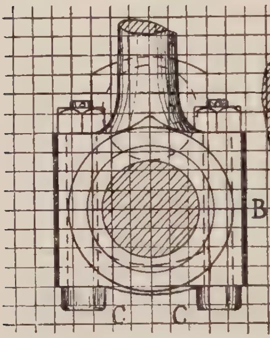


FIG. 71

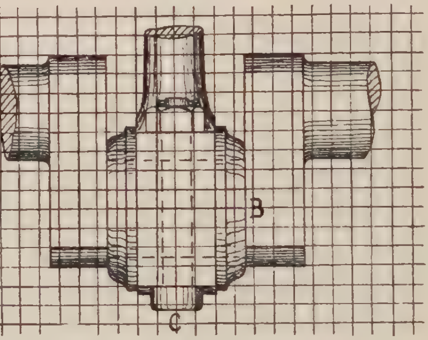


FIG. 72

THE GUIDE

When the pressure of the steam was used, by means of the cylinder and piston, to work a pump rod up and down to remove water out of a mine, the push and pull of the piston-rod on the down and up strokes of the piston were in a straight line with the pump rod, so there was no tendency to force the rod sideways and so bend it when applying the power to work the pump.

Now, however, when the force of the steam on the piston is used to make the crank shaft revolve, the power being transmitted from the piston through the piston-rod and cross-head, moving backward and forward in a straight line, to the crank pin, moving round and round in a circle by means of the connecting rod, we see that the forces brought into play are no longer acting in a straight line, the connecting rod, when pushing or pulling on the crank pin, being at an angle to the line of the piston-rod.

What is the result?

Let us take two straight pieces of wood, the one to represent the piston-rod and the other the connecting rod, and let us drive a nail through the ends of the pieces so that they shall be hinged together by the nail and free to move, as in the case of the piston and connecting rods, the nail taking the place of the cross-head pin.

If we place these two pieces of wood exactly in line, as shown in Fig. 73, where AB represents the piston-rod and BC the connecting rod, B being the cross-head pin and C the end of the connecting rod attached to the crank pin, D, the centre of the crank shaft, being exactly in line with these, then if we push directly down or pull directly up on the end A of the piston-rod, we see that there is no tendency for the point B to move sideways in either direction. This was the case with the steam-driven pump rod.

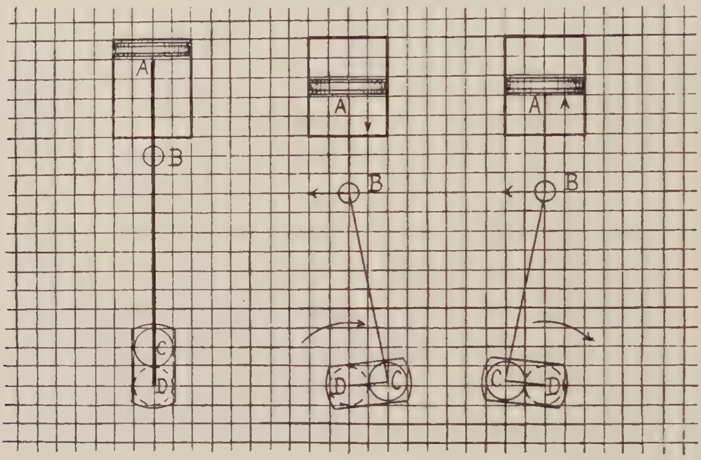


FIG. 73 FIG. 74 FIG. 75

Now let us place BC, the connecting rod, at an angle to AB, as it would be when the piston was half-way through its downward stroke, as shown in Fig. 74. If we now push down on A, we find that the point B tends to move in the direction shown by the arrow with considerable force. The greater the amount the pieces of wood are out of the straight line, the greater does this force become. Of course the tendency of this pushing down on A would be to cause the crank, if C were acting on a crank pin, to revolve in the direction shown by the curved arrow.

Again, if we set the connecting rod at an angle on the opposite side, as shown in Fig. 75, then on pulling up on A (as would be the case in making the crank revolve in the same direction as before), we find that the point B will still tend to force itself over in the same direction as in the last case.

In our engine, then, when driving the crank in one direction, whenever the piston is exerting force on the crank pin, the cross-head will always be trying to force itself over in the same direction, whether on the up or on the down stroke, with the result that the piston-rod will very soon bend and the engine be rendered useless.

To prevent this, it is necessary to arrange to support the rod on that side, but without in any way interfering with the free movement of the rod in its up-and-down course.

The simplest way to do this is to fix a strong metal plate or beam, called a "guide," exactly parallel to the piston-rod, and on that side toward which it is tending to bend. Then on that side of the cross-head we fix a strong metal block called the "guide slipper" or "shoe," which will just bear against the face of the guide, and moving backward and forward with the cross-head, to which the piston-rod is attached, will prevent the piston-rod from being bent, keeping it in its proper line without in any way hindering its motion. This arrangement is shown in Fig. 76, where

A Piston-rod.
B Connecting-rod.
C Cross-head.
D Guide.
E Guide slipper.
F Crank.

The direction of rotation of the crank is shown by the curved arrow in the sketch.

Of course, as in the case of the thrust block, and, in fact, of all bearing surfaces, we have to consider the subject of the intensity of pressure between the two rubbing surfaces, so that they may be efficiently lubricated to prevent friction and wear as far as possible. So we find that, as the "resultant force," as it is called, causing the slipper to press against the guide, is very considerable, it is necessary to have a guide slipper of considerable area to distribute the strain over sufficient surface of the guide.

This arrangement of guide and slipper is perfectly satisfactory so long as the crank only revolves in the one direction; but in a ship the engines must necessarily be able to revolve in both directions, so as to allow of going astern.

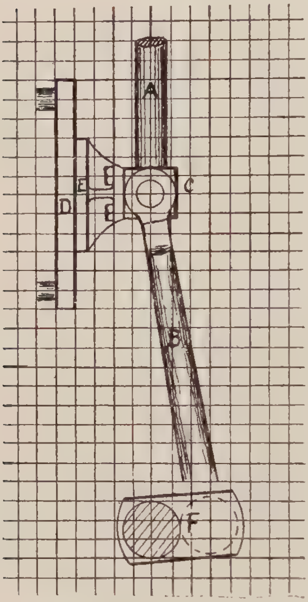


FIG. 76

If we go back to Figs. 74 and 75, and reverse the push and the pull on the piston-rod in the two cases so as to cause the crank to revolve in the opposite direction, then we see that the resultant force tending to bend the piston-rod acts in exactly the opposite direction, and so our guide, as shown in Fig. 76, is useless for going astern.

Consequently we must fit another guide and slipper to withstand this force when going astern.

The arrangement then becomes as shown in Fig. 77, where D′ is the "astern guide" and E′ the "astern slipper."

So now we have arranged for the satisfactory transmission of the power of the steam generated in the boiler, and acting on the piston and forcing it up and down in the cylinder, through the piston-rod, cross-head pin, connecting rod, crank pin, and crank arms, to the crank shaft, and so through the propeller shaft to the screw propeller, both for ahead and astern. Also we have arranged for the admission of steam, first to one end of the cylinder, and then to the other, and for the controlling of the exhaust, so we can make our propeller revolve and send our ship along.

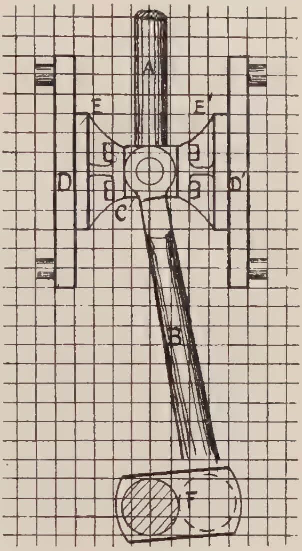


FIG. 77

METHOD OF WORKING THE SLIDE VALVE FROM THE CRANK SHAFT

In a ship it is necessary to be able to work the engines in both directions in order to propel the ship either ahead or astern at will, and we must be able to start with certainty in either direction.

Can this be done in an engine where the slide valve is worked by tappets?

Referring back to Fig. 60, we see that when the piston has nearly reached the lower end of its stroke, the tappet C on the piston-rod engages with the end of the lower tappet lever B, and forces the slide valve up, thus opening the lower steam port and so sending the piston back to the top of the cylinder. Now in Figs. 78 and 79 we see that the piston travelling toward the top of the cylinder will cause the crank to rotate in the direction shown by the curved arrows—the direction in Fig. 78 being opposite to that in Fig. 79. So if the engine were stopped with the piston in the position shown in the sketches, on admitting steam, say, to the bottom of the cylinder, by means of the slide valve, the piston would go up, but the crank in Fig. 78 would commence to rotate in the right-handed direction, or "with the sun," while that in Fig. 79 would start in the opposite or left-handed direction, and would continue so to revolve.

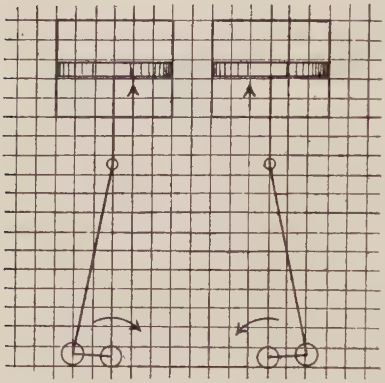


FIG. 78 FIG. 79

(We, in the Northern Hemisphere, when facing south, see the sun rise in the east or on our left hand, travel across from left to right and set on our right hand in the west, so this direction of motion is called right-handed or "with the sun," while the other direction is left-handed or "against the sun.")

This means that where the slide valve is worked by tappets the engine will start off in either direction equally easily, and we have no real control over the direction in which it is going to start.

Obviously this would not do, as we would be starting our ship ahead when we wanted her to go astern, or *vice* *versâ.* So we must dismiss the tappet as unsuitable for ship work, and something must be devised which shall be free from this objection.

Let us first consider how to drive the engine in one direction, and in that direction only.

The direction of motion of the crank being the point aimed at, the motion of the crank or crank shaft obviously suggests itself as the most suitable source of motion for working the slide valve.

We have seen how reciprocating motion is converted into rotary motion by the use of the crank. We now want to convert the rotary motion of the crank shaft back again into reciprocating motion, to work the slide valve. The most natural way to do this would be by means of another crank, fixed on the crank shaft, and moving the slide valve by means of a connecting rod attached to the slide rod.

As the "travel" (or distance moved from one end of the stroke to the other) of the slide valve is quite small compared to that of the piston, it is evident that the throw of a crank intended to work the slide valve, being equal to the half-travel of the valve, will be very much less than that of the main crank; also we must make the connecting rod for working the slide rod of such length that when the small crank is on its top centre the slide valve shall be at the top of its stroke—that is, that the bottom steam port shall be wide open to steam, and the top port wide open to exhaust. Then, of course, when the small crank is on the bottom centre the valve will be at the bottom of its stroke—the top steam port open to steam to its fullest extent, as the bottom port to exhaust.

Let us now consider in what position this small crank (which, on revolving with the crank shaft, will cause the slide valve to move up and down to the full extent of its stroke) must be placed relatively to the main crank to make the slide valve work in the necessary manner.

When the piston is at the top of its stroke, naturally the slide valve should be in such a position that it is on the point of opening the top steam port to steam, in order to send the piston down, and also the lower steam port should just have been shut off from steam, and on the point of opening to exhaust. We see that this is the case in Fig. 56, where the slide valve is in its middle position.

To get the valve in its middle position, the small crank must naturally be half-way between its top and bottom positions, and as the main crank is in its top position, the small crank will consequently be at right angles to it.

The positions of the various parts of the engine would then be as shown in Fig. 80, where the slide valve is shown on its side instead of flat (as it really would be), the better to show its action. The main crank, piston-rod, and connecting rod are shown by the dotted lines.

Now, if we turn the main crank the least little bit in the direction shown by the curved arrow, so as to get it off the dead centre, we see that the small crank moves downward, thus pulling the slide valve down and opening the top port to steam. This forces the piston down, and the main crank moves on in the same direction as we started it in. The small crank also moves in the same direction—that is, down—and so opens the steam port wider and wider as the piston approaches the middle of its stroke. When the main crank has moved to the position shown in Fig. 81, the small crank will have reached the bottom of its stroke and the steam port will be wide open, while the lower port will be wide open to exhaust.

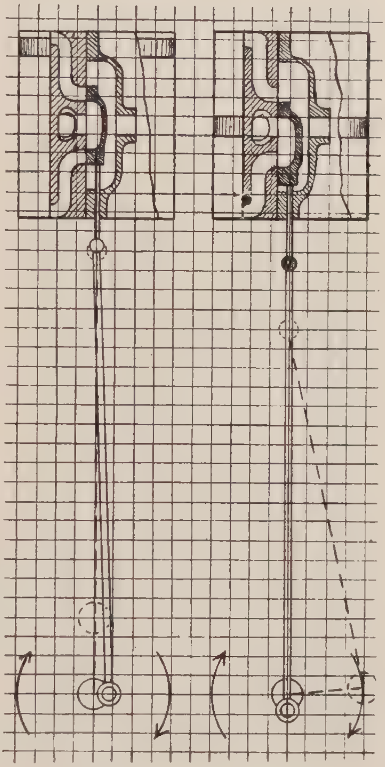


FIG. 80 FIG. 81

Then, as the main crank moves on towards the bottom dead centre, the small crank will be forcing the slide valve up again, and gradually closing the top port from steam and the bottom from exhaust. When the main crank reaches the bottom centre, the small crank will have pushed the slide valve up into its middle position and shut off both steam and exhaust, and the engine will be ready to start off on its return stroke.

Now let us suppose that when turning the engine off the dead centre we had turned it in the opposite direction to the arrow; the small crank would then, instead of moving down and opening the top port to steam, to send the piston down, have opened the bottom port, and so admitted steam under the piston, which would have gone up again and so shut off the steam. So the engine would be unable to start in that direction at all. We can see by studying the sketches that this would be the case from whatever position we tried to start the engine.

When the slide valve was moved back and forth by means of the tappets, we saw that the steam and exhaust ports were opened to their fullest extent almost instantaneously, thus allowing a very free passage for the steam into the cylinder from the very commencement of the stroke.

Now, however, with the slide valve worked by the small crank, we see that the opening of the ports is gradual, and that when the piston is near the end of the stroke, the ports are but little open. This would appear to be wrong, but as a matter of fact, it does not matter at all for the following reasons—

The speed of the piston varies very largely during the stroke, the piston actually coming to a standstill at either end. Consequently the rate at which the steam must enter the cylinder to drive the piston also varies largely during the stroke—from nothing when the piston is at the end of the stroke to a maximum when at the middle.

The speed of the slide valve also varies largely during the length of its travel, as it is driven by a crank.

It also comes actually to a standstill as its small crank passes over either dead centre, the valve being at the end of its travel, and the ports wide open.

When the piston is at the middle of its stroke, and so requiring much steam to drive it, we see that the small crank is at one or other dead centre, the valve at the end of its travel, and so the steam and exhaust ports wide open, which is exactly what we require.

Though the piston is moving at its fastest, the slide valve is moving at its slowest, and the ports remain practically wide open until the piston slows down toward the end of its stroke, by which time the small crank will have come round nearly to its mid-position, exercising its fullest effect in moving the slide valve, which consequently rapidly shuts off steam from the one end of the cylinder at the time that the piston is requiring but little to drive it, and again rapidly opens the steam port to the other end before the speed of the piston has yet become considerable.

Generally, when the piston is moving rapidly, necessitating a large flow of steam into the cylinder, the steam port is open to a considerable extent, while when the piston is moving slowly and but little steam is required, the ports, though partially closed, are yet sufficiently open to allow as much steam as is needed to pass.

Consequently the arrangement of the small crank set at right angles to the engine crank gives us a perfectly satisfactory distribution of steam to make the engine run smoothly, and entirely gets over the difficulty found with the tappets in not being able to make sure of the engine starting off in the desired direction, as it cannot by any possibility move except in the one direction.

As it is still necessary to be able to "reverse" the engine, it is quite obvious that we must have another similar small crank set at right angles to the engine crank, but on the opposite side, to work the slide valve when the engine goes in the opposite direction. Then by putting one or other of these two small cranks in connection with the slide valve, we can make absolutely certain of the engine going in the right direction.

THE ECCENTRIC

Though a small crank would work the slide valve perfectly satisfactorily, there would be some very serious objections to its use in an engine, especially in a ship, where space is so valuable. As there are generally two or more cylinders—each with its own separate crank acting on the same propeller shaft—it follows that the power of the foremost cylinder would have to be transmitted through the small crank for working the slide valve to that part of the crank shaft abaft it. Consequently that small crank would have to be made very strong and thick to withstand the strain, though the strength would not be needed for the actual working of the slide valve.

Strength means weight, and also space, which can ill be afforded, so the "eccentric" was devised to get over both of these objections.

The eccentric is really nothing more nor less than a crank pin of very large diameter, so large, in fact, that there is room for the crank shaft to be continued right through it, this crank pin combining in itself both crank pin and crank arms.

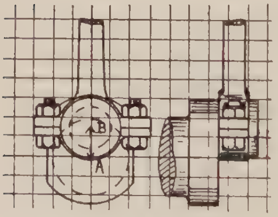


FIG. 82

We can see, in Fig. 82, that if A be the centre of the crank shaft, and B the centre of the crank pin, A B being the throw of the crank, it matters not in the least, so far as the result is concerned, what the size of the crank pin may be—the slide valve will be moved through exactly the same distance by the very large crank pin as by the small one.

Thus Fig. 83 shows the ordinary crank, with the throw A B, the crank pin being the same size as the crank shaft.

Fig. 84 shows the same crank, but with a much larger crank pin, the throw A B still remaining the same.

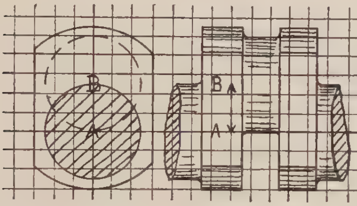


FIG. 83

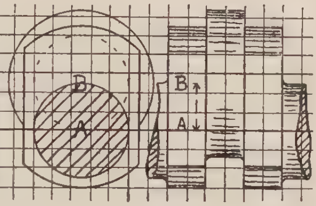


FIG. 84

In Fig. 85 the crank pin is still further enlarged, to such an extent as entirely to cover the crank arms—but the throw still remains the same, namely, A B, the distance from the centre of the crank shaft to the centre of the crank pin. Now, as the crank arms are entirely covered by this very big crank pin, they become

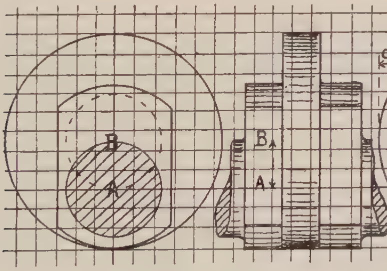


FIG. 85

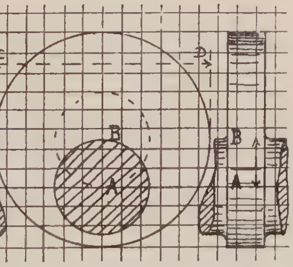


FIG. 86

unnecessary, and so can be done away with, the big crank pin only remaining, as shown in Fig. 86.

In actual practice, instead of making this big crank pin on the shaft, a flat round disc of metal of the same diameter C D is used, a hole the size of the shaft being made through it, with the centre A, and through this hole the shaft passes, the disc (which is called an eccentric) being firmly secured to the shaft so that it cannot move on it and will go round with it. The distance A B, which is the throw of the crank necessary to work the slide valve, in the eccentric is also called the throw, or the "equivalent crank arm."

In a crank, the end of the connecting rod which is attached to the crank pin is furnished with a "crank-head bearing" in which the crank pin revolves. So with the eccentric, a bearing similar in principle is required for connecting the rod which works the slide rod to the eccentric.

In this case, however, the power to be transmitted is comparatively small, so this bearing, instead of being very heavy and strong as is the crank-head bearing, is quite light, and forms practically a strap, encircling the eccentric.

The rod connecting this "eccentric strap" to the slide rod is called the "eccentric rod."

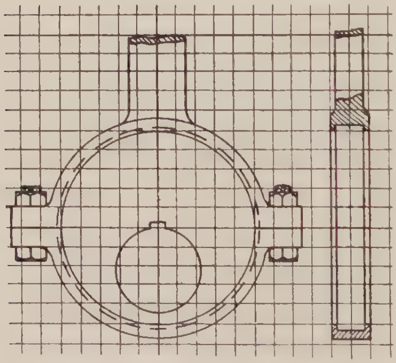


FIG. 87

The arrangement of the eccentric and eccentric strap is shown in Fig. 87, the strap being in two halves for the same reason as is the crank-head bearing.

By the substitution of this eccentric (which may be comparatively thin) for the short-throw crank with its two strong arms and its pin, for working the slide valve, we save a deal of valuable space, we greatly reduce the weight, and also the cost of manufacture.

As two of these eccentrics are required, the one for working the slide valve when going ahead, and the other when going astern, this saving is a very important matter.

ARRANGEMENT FOR CONNECTING EITHER ECCENTRIC ROD TO THE SLIDE ROD

The first plan used for this purpose was somewhat crude. When it was necessary to reverse the engine, the eccentric rod which had been working the slide valve was disconnected, and before the engine had stopped the other eccentric rod was brought into place so that it would connect with the slide rod when it came into the proper position.

This was done by furnishing each eccentric rod at its upper end with what was called a "gab" — a recess which would drop over a pin on the end of the slide rod when it came opposite to it, and so would connect that eccentric rod to the slide rod. This arrangement is shown in Fig. 88, where the two eccentric rods were "linked" to-

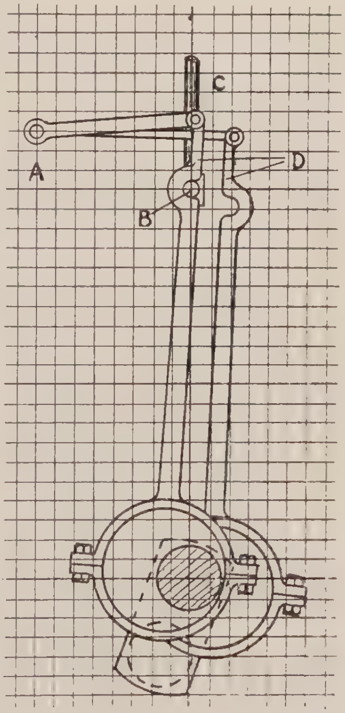


FIG. 88

gether at the top ends, and by means of the lever A the gab of either eccentric rod could be brought into connection with the pin B on the slide rod C, and so work the slide valve. The spurs D D above the gabs merely served to guide the gab on to the slide-rod pin.

This was a very poor arrangement, as when reversing the engine, for a time the slide valve was entirely out of control, not being connected with either eccentric. If the engine should stop with neither eccentric connected, it had to be turned by hand until the right eccentric was connected by means of its gab.

Stephenson, who built the first locomotive, solved this problem by means of what is known as "Stephenson's Link Motion," by means of which the slide rod was never out of connection with the eccentrics.

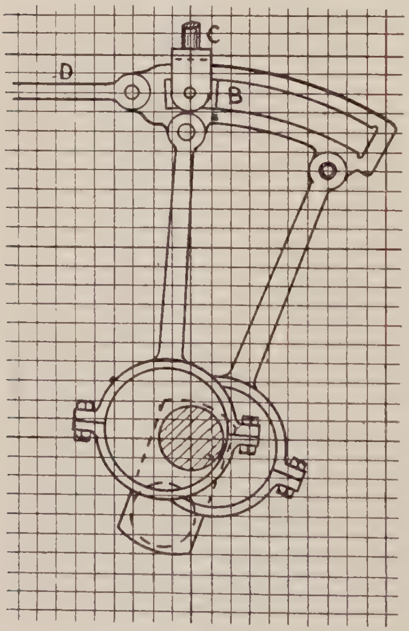


FIG. 89

This arrangement, shown in Fig. 89, is still very largely used, the most modern arrangements being merely adaptations of his plan. He simply linked the top ends of the two eccentric rods together by means of a plate called the "link," and in this link was cut a slot or channel, curved with the centre of the crank shaft as the centre of the curve. In this slot was fitted a metal block B called the "link block," and in this block worked a pin on the end of the slide rod C.

So the slide valve always being in connection with the link block, was also always in connection with both eccentrics, the eccentric rods being attached to either end of the link by hinge pins. By means of a "drag link" D, worked by a suitable lever, the link could be "dragged" over so as to bring the end of either eccentric rod directly beneath the link block, and so put the slide valve in direct communication with either eccentric, by which means the engine could be made to go either ahead or astern, or could be reversed without shutting off steam.

With this arrangement both eccentrics were always more or less acting on the slide valve, as even when the one eccentric rod was directly beneath the link block, the other eccentric was also acting on it through the swaying motion imparted to the link. This, as will be seen later on, was really rather a good thing, as when working at low powers an economy of steam could be effected.

Another very valuable point is gained by this arrangement. By "middling the link," that is, bringing it into its middle position, both ahead and astern eccentrics will be brought equally into action on the slide valve, and so the engines can be stopped without even shutting off the steam.

CHAPTER IV

"EXPANSIVE" WORKING OF THE STEAM ENGINE

WE must now go back a long way—to Boyle's Law, treating of the relation between the pressures and volumes of gases. In Fig. 50 we have a diagram showing the pressures on a piston working in a cylinder 1 ft. in sectional area, into which was introduced 1 cubic foot of steam at a total pressure of 150 lbs. per square inch, or 135 lbs. above atmospheric pressure. When the piston is at 1 ft. distance from the back end of the cylinder, that is, when the space behind it is the original 1 cubic foot taken up by the steam, pressing outward in all directions with a force of 150 lbs. on every square inch of area, this steam pressure tends to move the piston along the cylinder with a force of over 9 tons.

As the piston travels along the cylinder, the steam behind it expanding into the larger space, the pressure falls as the space increases, and when the piston has moved a foot further along the cylinder, giving double the space for the steam, the pressure has fallen to half of the original pressure, that is, 75 lbs. per square inch, and the force with which it is now tending to move the piston further along the cylinder is still nearly 5 tons. When the piston has moved 2 ft. further still, and the steam has expanded into four times the original volume, the pressure is $\frac{150}{4} = 37\frac{1}{2}$ lbs., exercising a force of nearly $2\frac{1}{2}$ tons on the piston, and so on. In each of these cases, the effective force on the piston must be reduced by nearly a ton, on account of the 15 lbs. pressure of the atmosphere acting on its face, and working against the steam pressure on its back.

In our steam engine, with the simple slide valve, we admit steam at boiler pressure into the cylinder throughout the stroke, so when the piston reaches the end of the stroke we have the cylinder full of steam at boiler pressure. The slide valve now opening the exhaust to allow of the return stroke, lets this cylinder-full of steam at a high pressure, and which is still capable of doing a deal of work, escape to the atmosphere—all the power contained in the steam being wasted. To reduce this waste, or rather, to turn into useful work a larger proportion of the power contained in the steam, we must arrange to utilise this expansive force of the steam.

Considering our cylinder in Fig. 50, with the total pressure of 150 lbs. per square inch, or ten atmospheres, when the piston has travelled 9 ft. further along the cylinder, thus leaving a space of 10 cubic feet behind it, the steam will have expanded to ten times its original volume, and the pressure will have fallen to one-tenth of the original pressure, or one atmosphere, and so it will be unable to drive the piston any further, the pressure on either side now being the same.

In our engine, if we were using steam at 150 lbs. total pressure, or 135 lbs. above the atmosphere, as shown by the pressure gauge, and were to "cut off" when the piston had only moved one-tenth of its stroke, then by the time the piston reached the end of its stroke, the pressure would have fallen to one-tenth of the original 150 lbs., that is, it would have fallen to 15 lbs. or one atmosphere, and would be exercising no force at all on the piston, as the 15 lbs. pressure of the atmosphere is all the time acting against it on the front of the piston.

We would have used up all the available power in our one-tenth of a cylinder-full of steam.

In the diagram given in Fig. 90, the length of the diagram representing the length of the stroke, and being divided into ten equal parts, we see how the pressure falls during the stroke, the pressure at any point of the stroke being shown by the height of the curve E C above the base line.

Let us, with the aid of this diagram, study what happens as regards the power to be obtained from the steam.

Let us apply this in a particular case—our cylinder in Fig. 50, of 1 square foot sectional area and 10 ft. long. Suppose we had admitted steam throughout the stroke, then we would, for each stroke of the piston, have used 10 cubic feet of steam at a total pressure of 150 lbs. per square inch. The force exercised on the piston, due to this pressure of 150 lbs., would be

$$144 \times 150 = 21{,}600 \text{ lbs.}$$

Against this would be acting the pressure of the atmosphere, so we must deduct

$$144 \times 15 = 2{,}160 \text{ lbs.},$$

giving us an actual forward or "effective" pressure on the piston of

$$21{,}600 - 2{,}160 = 19{,}440 \text{ lbs.}$$

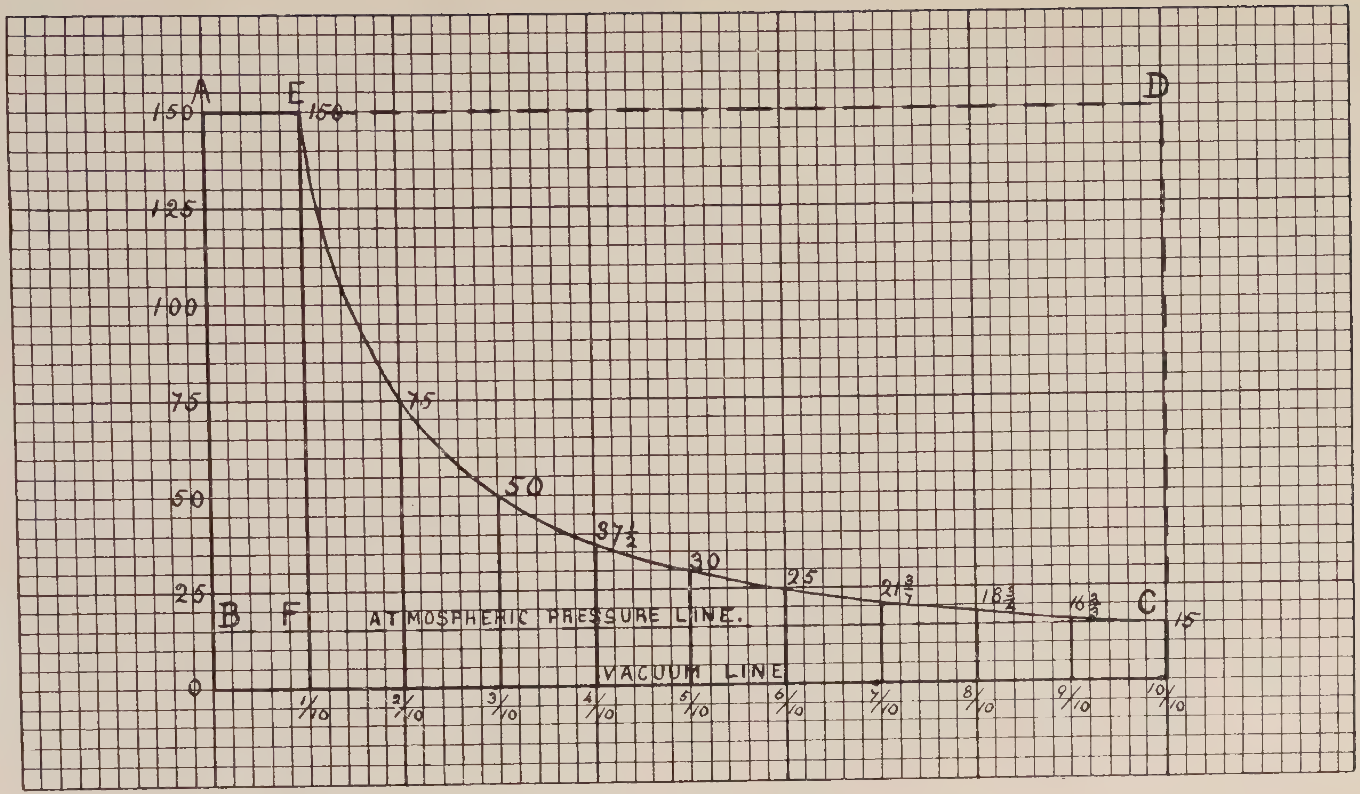

A
E
D
150
150
125
100
75
75
50
50
37½
30
25
25
21 3/7
18 3/4
16 2/3
C
15
B
F
ATMOSPHERIC PRESSURE LINE.
VACUUM LINE
0
1/10
2/10
3/10
4/10
5/10
6/10
7/10
8/10
9/10
10/10

FIG. 90

So our 10 cubic feet of steam at the total (or "absolute") pressure of 150 lbs. would be able to lift a weight of 19,440 lbs. from the bottom to the top of the cylinder, if it were placed vertically, a distance of 10 ft.

The "British unit of work," to which all power is compared, is "the work done in lifting a mass of 1 lb. avoirdupois through a height of 1 foot," and this is called a "foot-pound." (As an illustration, suppose our weight to be 8 stone, or 112 lbs., then the work we do in climbing up a hill 100 ft. high is $112 \times 100 = 11{,}200$ foot-pounds.)

In the case of our cylinder, then, the work done by the 10 cubic feet of steam would be

$$19{,}440 \times 10 = 194{,}400 \text{ foot-pounds,}$$

and this would be represented on our diagram (Fig. 90) by the area of the rectangle A B C D.

Now let us consider what happens when we cut off the steam when the piston has travelled through one-tenth of its stroke. The amount of steam used for each stroke of the piston would be 1 cubic foot.

For the first one-tenth of the stroke, the piston would exercise a force of $144 \times 150 - 144 \times 15 = 19{,}440$ lbs., and so would do 19,440 foot-pounds of work.

In the second tenth of its stroke, the force on the piston would commence by being 19,440 lbs., as the pressure of the steam was the full 150 lbs.; but by the time the piston reached the end of the second tenth, the pressure would have fallen to 75 lbs., and the force on the piston would then be only 8,640 lbs. By the time the piston had reached the end of the fourth tenth the pressure would have fallen to 37·5 lbs., giving an effective pressure on the piston of $37{\cdot}5 - 15 = 22{\cdot}5$ lbs.

per square inch, with an effective force of 144 × 22·5 = 3,240 lbs.

At the end of the eighth tenth, the pressure would have fallen to 18·75 lbs., giving an effective pressure of 18·75 – 15 = 3·75 lbs., and an effective force on the piston of 144 × 3·75 = 540 lbs.

Finally, at the end of the stroke, the pressure having fallen to 15 lbs., the effective pressure would be 15 – 15 = 0 lbs., and there would be no effective force at all on the piston.

So, for the last nine-tenths of the stroke, the effective pressure on the piston would be the average of the effective pressures at all times during that part of the stroke, and the average force on the piston would be this average pressure × 144.

Working out the average pressure from the diagram in the usual way, by adding all the "ordinates" together and dividing the sum by their number, we find this pressure to be 37·1 lbs., which gives us an average effective pressure on the piston of 37·1 – 15 = 22·1 lbs.

As this is the average force acting through nine-tenths of the stroke or 9 ft., the work done by the one-tenth cylinder-full of steam (1 cubic foot) in expanding down from the original pressure of 150 lbs. to the pressure of the atmosphere is 3,182 × 9 = 28,638 foot-pounds.

In the diagram this amount of work is represented by the area of the figure ECF.

We saw that during the first tenth of the stroke (at the end of which the steam was cut off) the work done was 19,440 foot-pounds. To this we must now add the 28,638 foot-pounds of work done by the expansion of the steam after it was cut off, giving us a total of 48,078 foot-pounds as the amount of work 1 cubic foot of steam at 150 lbs. absolute pressure is theoretically capable of doing, when expanded down to atmospheric pressure.

As the same quantity of steam, used non-expansively, is, we have seen, capable of doing only 19,440 foot-pounds of work, we see what a large amount of power is wasted by not utilising this expansive force.

In actual practice, a number of points which will be considered later greatly affect this result, making it impossible to use nearly such a high "ratio of expansion" as we have taken here—that is, we cannot, in a simple engine of the type we have considered so far, satisfactorily get the work out of the steam by "cutting off" as early as one-tenth of the stroke and letting its expansion send the piston along through the remaining nine-tenths of the stroke.

These practical considerations set the most suitable point for the "cut off" at somewhere near the middle of the stroke.

ARRANGEMENT OF THE SLIDE VALVE FOR EXPANSIVE WORKING

In order to cut off the steam before the piston reaches the end of its stroke, the slide valve is made wider, so that when it is in its middle position it will overlap the steam ports in the cylinder face, as shown in Fig. 91, the throw of the eccentric being increased to the same amount as the slide valve overlaps the ports, in order that the ports shall open to the same extent as before, when the valve is at the end of its stroke.

Obviously, then, the steam port will be shut off by the slide valve before it reaches its middle position, and so before the piston reaches the end of its stroke, and the piston then will be driven for the rest of the stroke by the expansive force of the steam in the cylinder; when it reaches that point, the slide valve, having reached its middle position, will open the exhaust to allow of the return stroke. But owing to the overlapping of the slide valve beyond the steam port (the amount of which overlap is called the "lap" of the slide valve), the steam port will still be closed, and there will be no steam to start the piston on its new stroke. Naturally this would not do, so, in order to bring the valve into position to be on the point of opening the port to steam, it is evident that we must pull the slide valve down to an amount

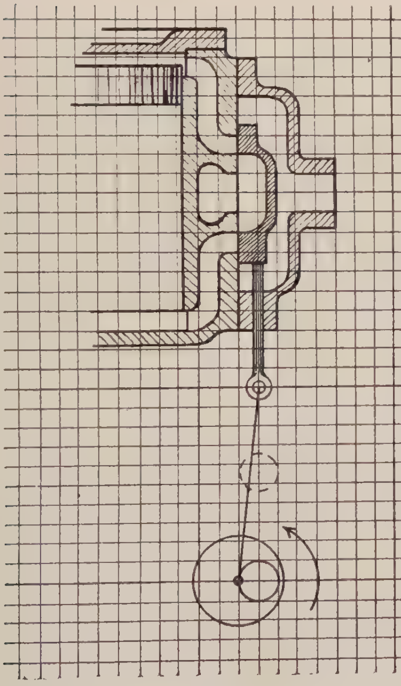


FIG. 91

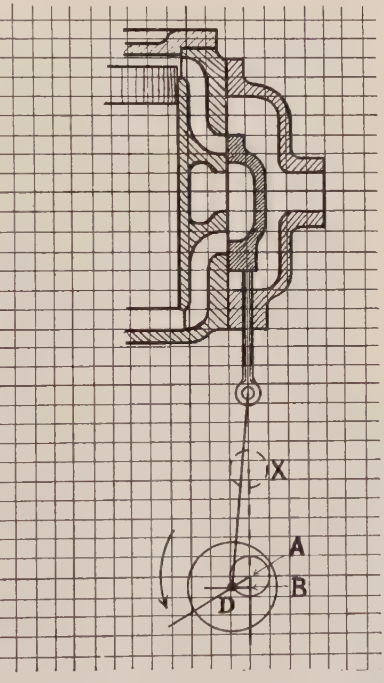


FIG. 92

equal to the lap (if the piston be considered as at the top end of the cylinder).

This will bring the top edge of the slide valve level with the top edge of the upper steam port, and so, on moving the engine off the dead centre in the right direction, the port will at once commence to open to steam.

To find how far the eccentric must be advanced beyond the right angle ahead of the crank, let us mark on a vertical line beneath A, the centre of the crank shaft, and thus directly opposite the crank, which is on the top dead centre, a distance A B equal to the lap of the slide valve, as shown in Fig. 92. From this point mark a horizontal line B D, cutting at D, a circle marked on the end of the crank shaft, and representing the circle described about the centre of the crank shaft by the centre of the eccentric, the radius of this circle being equal to the throw of the eccentric.

Then, if we twist the eccentric round on the shaft until its centre coincides with this point, and fix it in that position, the slide valve will have been lowered by the desired amount, and the upper steam port will be just opening to steam, being in the position shown in Fig. 92.

In this operation, if the circle described about the centre of the crank shaft by the centre of the eccentric be larger than the end of the crank shaft, the circle, instead of being marked on the end of the crank shaft itself, must naturally be marked on the eccentric, and the line A D, marked on the crank shaft, to act as a guide in setting the eccentric in the right position.

Let us now consider what other effects this "advancing" of the eccentric beyond the right angle ahead of the crank will have, beside the causing the steam port to open at the commencement of the stroke.

The point of admission we have made the same as before, and the point of cut-off is earlier. On the inside or exhaust side of the valve, where no alteration has been made as regards the shape of the valve, the effects of the motion of the valve are felt earlier with respect to the position of the piston. So, instead of the exhaust closing when the piston comes to the end of the stroke, it does so some time before, and naturally also the pressure driving the piston forward is relieved earlier by the opening of the exhaust.

We have seen what is effected by the advancing of the eccentric as regards the admission and cut-off of the steam.

What are the effects of the earlier closing of the exhaust port on the side toward which the piston is moving and the opening of that on the other side?

We know what happens when we collide with something solid, when moving at any speed. Well, the piston, piston-rod, and connecting rod, weighing, in a large engine, a matter of some tons, are moving decidedly fast before they reach the end of the stroke, and the strain on the crank-head bolts and other parts of the engine consequent on the sudden stoppage and reversal of this heavy mass moving at considerable speed, would be enormous, and would not tend to turn the crank, so would be doing no useful work.

So the early closing of the exhaust is decidedly useful.

The steam (at low pressure) behind the piston, being unable to escape, is "compressed" by the moving piston, and consequently its pressure increases as its volume is reduced, and it acts as a "cushion" or buffer, which checks the momentum of the heavy moving mass gradually, instead of letting the crank head do it suddenly, and so reduces the strain on the parts of the machinery in the same way that a mattress in the gymnasium checks the speed of our fall gradually when we make a mistake on the horizontal bar.

Similarly, the earlier opening of the exhaust is a good point, as it has the same result, to a certain extent, as has "compression," which is the name given to the squeezing up of the remains of the exhaust steam on the side toward which the piston is moving.

By this early "release" the pressure tending to drive the piston forward is relieved, and so, with the help of the compression or "cushioning," the shock due to the stoppage of the motion of the piston is reduced almost to nothing.

The early release can very easily be carried too far, however; too much of the useful power of the steam may be lost, and so to prevent release happening too soon the slide valve is made with a certain amount of lap on the inside, or exhaust side, as well as on the out, or steam side.

Naturally this is called "inside lap," and is also useful in making compression take place somewhat earlier still, which further increases economy, as the cushioning of the remains of the exhaust steam fills the port and "clearance space" at the end of the cylinder with steam at or about the full working pressure, ready to assist the new steam which enters on the opening of the steam port to start the piston on its return journey, and so saving that amount of new steam and effecting a considerable saving of fuel.

So we see that the four duties of the slide valve are carried out in the following order—

(1) Admission. (3) Release.
(2) Cut-off. (4) Compression.

LEAD

We have seen that cushioning checks the momentum of the moving mass of piston and rods, but the pressure, unless the exhaust be closed very early, does not rise high enough to do this as thoroughly as it should do, the space into which the remains of the exhaust steam, at exhaust pressure, is compressed, being considerable, including as it does, not only the clearance space between the piston and the cylinder end at the end of the stroke, but also the steam port (as far as the valve face), which practically forms part of the cylinder.

So it is found necessary to open the steam port to steam a little before the piston reaches the end of the stroke, so that the full pressure of the steam shall be used to check the piston.

To do this the eccentric is still further "advanced" ahead of the crank. So, when the piston reaches the end of its stroke and the crank is on its top dead centre, the slide valve will be below its mid-position by an amount equal to the lap added to the amount the steam port is open at that time.

To find the proper position for the eccentric on the crank shaft on the same method as we employed in Fig. 92, we mark, in Fig. 93, on the vertical line X Y and below A, the centre of the crank shaft, X A being the crank, in addition to the distance A B, which equals the lap, a further distance B C, equal to the amount we wish the port to be open to steam when the piston reaches the end of the stroke (this amount is called the "lead" of the slide valve), and through the point C draw the horizontal line C D, cutting the circle described by the centre of the eccentric at D. Then A D will be the position of the throw of the eccentric, and the eccentric must be fixed on the shaft with its centre at the point D.

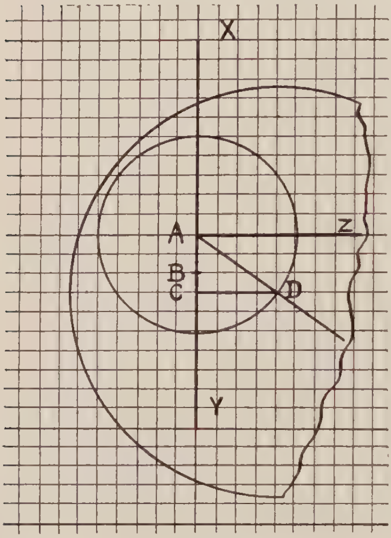


FIG. 93

The angle Z A D, which is the angle the eccentric throw is in advance of the original right angle ahead of the crank, is called the "angle of advance," or "angular advance," of the eccentric.

Naturally this further advance of the eccentric causes all the operations of the slide valve to take place still earlier in the stroke. Thus, beside the main object of the extra advance—earlier admission—we also get earlier cut-off, release, and compression, with a corresponding increase of economy and diminution of shock to the parts of the machinery.

THE TWO-CYLINDER ENGINE

So far we have considered the engine as having only one cylinder, though by having the second crank arm and the continuation of the crank shaft beyond the crank, we have made allowance for another cylinder to be arranged conveniently near the first one.

The object of a second cylinder acting on the shaft is, primarily, to get more power to bear on the one shaft than can conveniently be given by one cylinder, on account of the size this cylinder would require to be.

In addition to this there are also other and very important purposes served by having a second cylinder.

When the simple slide valve was used, having neither lap nor lead, and admitting steam throughout the stroke, the engine was always in a position to start, except when the crank was exactly on either dead centre, as one or other steam port was always more or less open to steam, and so ready to start the piston moving, except at these two points. It was a comparatively simple matter to avoid stopping the engine on the dead centres, and so there was seldom any difficulty about starting.

Now, however, with the slide valve having both lap and lead, it is quite a different matter, as for a considerable part of the stroke both steam ports are entirely closed, and so the engine is unable to start. Also, owing to the steam being used expansively, for the sake of economy, the force exerted by the piston is much less toward the end of the stroke than at the beginning, with the result that the crank shaft would move jerkily—to get over which a heavy fly-wheel is needed, the momentum of which will take up power when the force is great, to give it back again when it is small, thus causing the shaft to revolve more or less steadily. Also, when working very slowly, the momentum of the fly-wheel is required to carry the engine over the dead centres.

When two cylinders are used, if the cranks be arranged opposite each other, as shown in Fig. 94, the power will be doubled all right, but there will be the same difficulties as before, as both cranks will be on dead centre at the same time, and both pistons will be exerting their maximum, as also their minimum, force at the same time. We can get very much more benefit from the use of the two cylinders than the mere doubling of the power, and that without sacrificing anything.

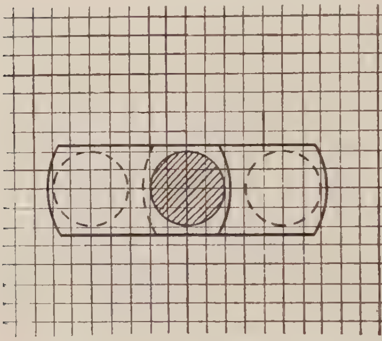


FIG. 94

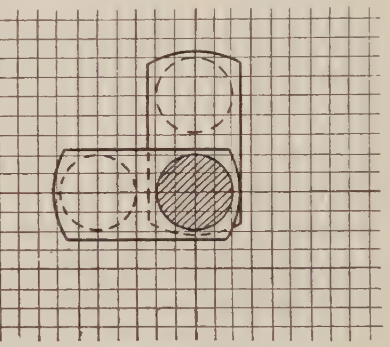


FIG. 95

We arrange the cranks at right angles to each other, as shown in Fig. 95. Then we see that when the crank A is on dead centre, B is in the middle position, and the piston acting on it to the best advantage, and with its maximum force. So B helps A over its difficulty. Also, when the piston acting on B is getting near the end of its stroke, and its force has considerably diminished, that acting on A will be nearing its mid-position, and so acting at its best advantage.

Thus the total force from the two cylinders, making the crank shaft revolve, becomes practically constant, and the engine works steadily.

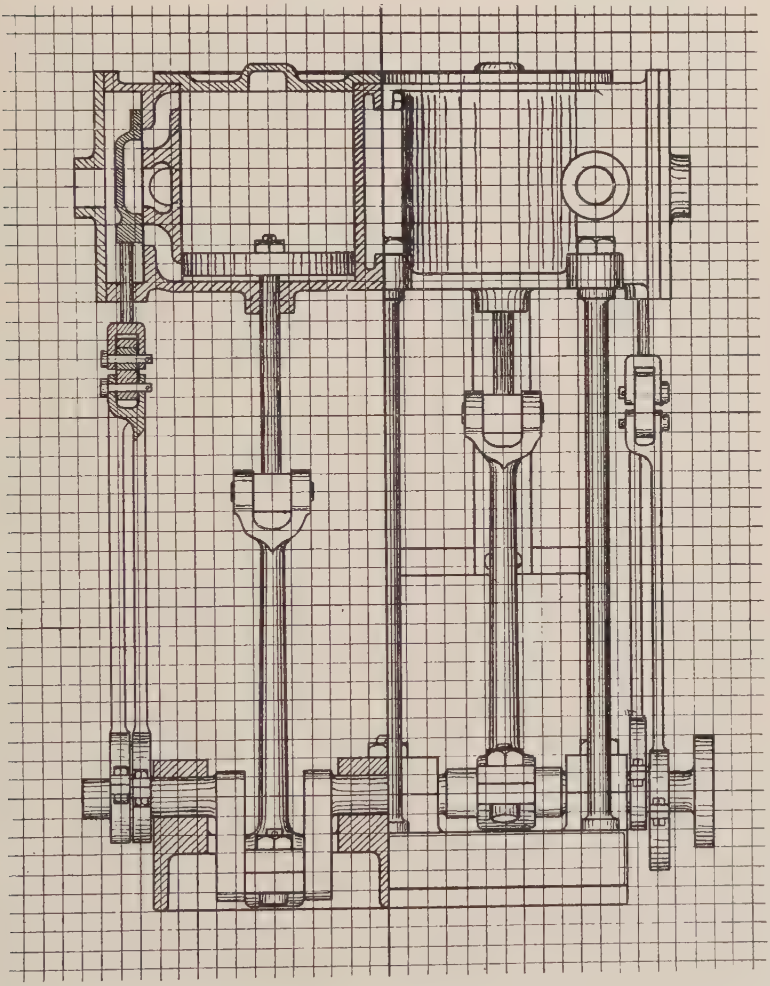


FIG. 96

Another very important advantage is gained, in that when the engine is stopped and we wish to start it, if the slide valve of A's cylinder is in such a position as to shut off steam from both ends of the cylinder, then the slide valve of B's cylinder will be in position to admit steam to one or other end of its cylinder, and the engine will start and move until A's slide valve uncovers a steam port, when A's cylinder also will commence to work. So, with the two-cylinder engine, with the cranks at right angles, it will start from any position, as each cylinder with its own crank and slide valve forms a complete engine entirely independent of the other, and ready to help it over its dead centres and shut-off positions.

The general arrangement of a two-cylinder simple engine is shown in Fig. 96.

This brings us up to the modern steam engine, of the type used in most locomotives, and in many land engines where a plentiful supply of water is not available for utilising the power still remaining in the steam when it reaches atmospheric pressure, by removing even this pressure from the front of the piston on the return stroke by reducing the volume of the 10 cubic feet of steam at atmospheric pressure, or 15 lbs., in Fig. 90 (representing a force of nearly a ton on the piston), back again to the original 10 cubic inches of water from which we started, and so leaving a "vacuum," or void, of nearly 10 cubic feet into which the piston can travel back without any resistance at all, a power represented in Fig. 90 by the area of the rectangle beneath the "atmospheric line."

CHAPTER V

DETAILS OF THE MECHANISM

HAVING now briefly sketched the general principles on which the steam engine is constructed and the manner in which it works, we are in a position to consider in greater detail the various parts of the engine and how they are made to work in practice.

THE PISTON

When considering the piston working steam-tight in the cylinder, in Fig. 48, we said that the piston was made to fit the cylinder so perfectly that no steam could leak past it, yet the piston was perfectly free to move along the cylinder without offering any resistance through its friction with the walls of the cylinder.

This is manifestly impossible, for even supposing that this perfect fit could be obtained, when the cylinder and piston were heated to the temperature of the steam the expansion of the metal of the piston and the cylinder would not be so perfectly even but that either the piston would be slack in the cylinder and allow steam to leak past, or else it would be so tight that the friction would cause great resistance to the movement of the piston along the cylinder, or even prevent the piston from moving at all.

To get over this it is necessary to make the piston "elastic," so that it will yield and become smaller if it be too tight in the cylinder, and expand or become larger if it be too loose, thus keeping a steam-tight joint.

PISTON PACKING RING OR SPRING RING

In practice, the "body" of the piston is made such a free fit in the cylinder that it never actually touches the sides at all. The actual steam-tight joint between the piston and the sides of the cylinder is obtained by means of a "floating" elastic ring, called a "packing ring" or "spring ring," practically forming a part of the piston, but free to open and close to a limited extent, and kept pressed out against the sides of the cylinder by means of springs between it and the body of the piston.

This ring is made a little larger in diameter than the cylinder, and a small piece is cut out of its circumference in a slanting direction, so that it can be "sprung" into the cylinder, when the ends of the ring come very nearly together, and the ring, owing to its larger diameter, tends to spring out and fit closely against the sides of the cylinder, so making the necessary steam-tight joint, being assisted in this by the "piston springs" mentioned above.

If merely a groove were cut round the circumference of the piston to receive this ring, the ring could not be got into its place in the piston, so, to allow this to be done, the groove is made one sided, and a strong metal ring, called a "junk ring," is fixed to the other side of the piston by means of nuts on studs screwed into the body of the piston, so that it practically forms a part of the body of the piston and keeps the packing ring in place.

If steam were to leak in between the body of the piston and the back of the ring, the pressure of the steam would tend to expand the packing ring out against the sides of the cylinder with such force as to cause great friction, wasting much power, and rapidly wearing out both ring and cylinder. To prevent this from happening, the joint between the junk ring and the body of the piston is made steam-tight, and the ring is made to fit the sides of the groove so perfectly that though it is free to move, yet steam cannot leak in behind the ring.

As the ring wears, the opening where it is cut naturally becomes wider, and steam would leak through to the other side of the piston and also in behind the ring.

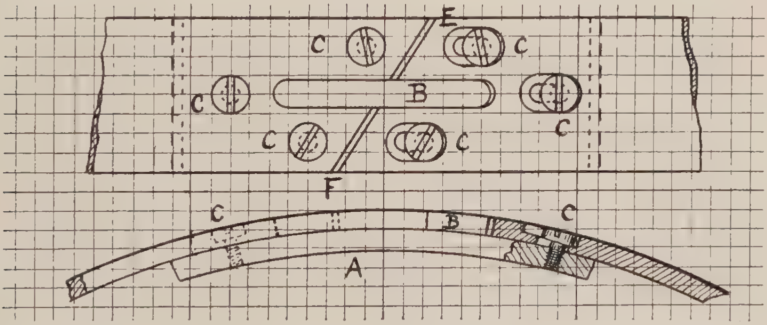
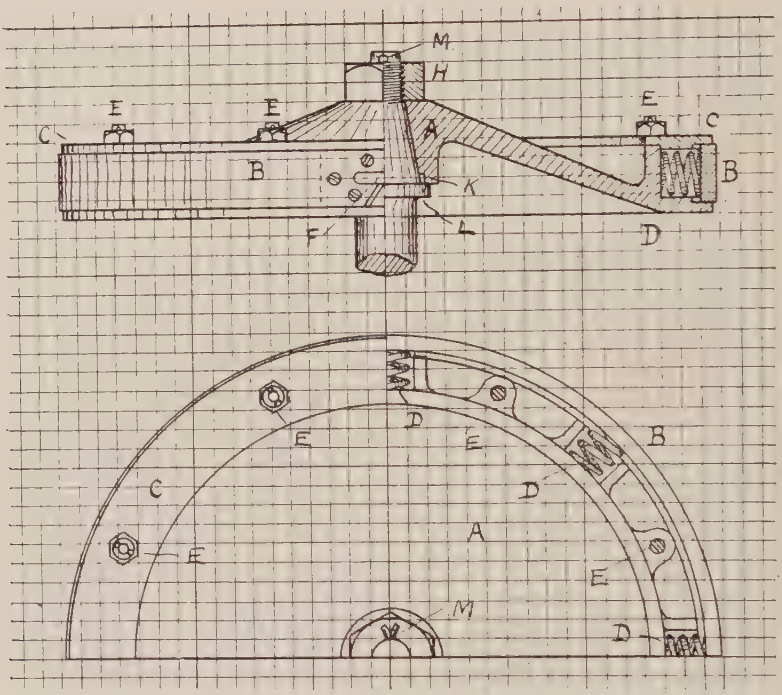


FIG. 97

To prevent this, a plate A in Fig. 97 is fixed by bolts C C to one end of the packing ring behind E F, the cut in the ring, and on this plate is a "tongue-piece" B, fitting into a groove cut part in each end of the ring.

This allows the ring to expand, but prevents the steam from passing.

The arrangement of such a piston is shown in Figs. 98 and 99, where A is the body of the piston, B the packing ring, C the junk ring, D the piston springs, E the studs for securing the junk ring, and F the tongue-piece.



FIGS. 98, 99

There are many other forms of packing ring beside this broad one shown in Figs. 98 and 99. For high pressures, it is more usual to have a number of narrow rings instead of the one broad one. These narrow rings do not always have springs behind them, to keep them pressed out against the sides of the cylinder, but trust only to the spring in the rings themselves. Such rings are generally made of steel or phosphor bronze (a specially hard and elastic kind of bronze).

The arrangement of a piston with narrow rings is shown in Fig. 100. In comparatively small pistons, these rings are often simply sprung into grooves turned in the circumference of the piston, when the junk ring is dispensed with. In this case there is no tongue-piece, the cuts in the different rings being so placed that they shall not come opposite each other. Piston rings of this type are known as "Ramsbottom" rings, the arrangement being shown in Fig. 101. Narrow rings are now very generally made so that they cannot spring out more

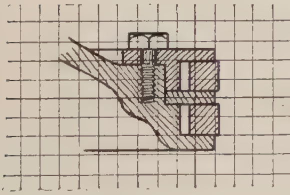


FIG. 100

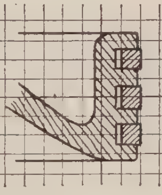


FIG. 101

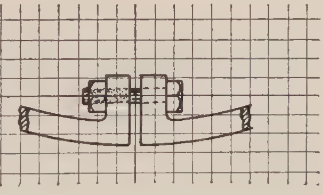


FIG. 102

than a fixed amount: one way of doing this is shown in Fig. 102.

This settles the point of how the piston is made to work steam-tight in the cylinder, and to remain steam-tight even when worn.

METHOD OF SECURING THE PISTON ON THE ROD

The piston is secured to the piston-rod much in the same manner as is the propeller to the shaft (Fig. 36), namely, by making a cone at the end of the rod, on which cone the piston is held by a nut. As there is practically no tendency for the piston to twist round on the piston-rod in Fig. 98, only a small "stop," K, is used, instead of the big "key" in the case of the propeller, which had to transmit the whole of the torsion of the shaft to the propeller.

Also it is usual to have a "collar," L, on the piston-rod, against which the under side of the piston bears, so that when the piston-rod nut H is screwed hard home, the piston cannot be forced along the cone. To prevent the nut from "slacking back," a pin, M, is put through a hole in the end of the rod, half fitting into grooves in the face of the nut.

STUFFING BOXES AND GLANDS

The next detail we must consider in the practical steam engine is the matter of how the piston-rod is made to work steam-tight through the end of the cylinder in Fig. 52.

This is done, as in the case of the piston, by means of packing; of course it cannot be done by making the piston-rod expand outward to fit the hole, as did the piston, so the packing is arranged to squeeze inward against the rod, and instead of moving back and forth as does the piston packing ring, is fixed in a "box" called a "stuffing-box" in the cylinder cover. The hole through which the piston-rod passes is made to fit the rod for a short distance only, being bored out considerably larger than the rod for some distance, leaving an "annular" space round the rod. Into this space, which is really a round box, is "stuffed" the packing, which is of some soft and easily compressible material, with a certain amount of elasticity, made into a sort of rope, for convenience.

This material must of course be able to stand the heat of the steam, and the friction of the rod as it works up and down through it.

To keep the packing in the stuffing box, and squeezed in against the rod, a "gland" is fitted round the rod and is inserted into the mouth of the stuffing box, which it fits, and by means of studs and nuts, it is forced against the packing.

It is usual in all large work, and also in most small, to fit a "neck bush" of gun metal in the bottom of the stuffing box, this neck bush being a slack fit on the rod and acting as a sort of guide for the rod. If the rod should touch the neck bush, the gun metal, being softer than the rod, will wear away first, and can easily be replaced if necessary.

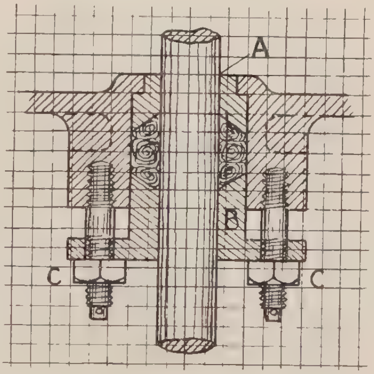


FIG. 103

The inside faces of the neck bush A and the gland B in Fig. 103 are sloped as shown in the sketch, so that the tendency is, on screwing up the gland by means of the nuts C C, not only to compress the packing but also to force it in against the rod by the wedge action of these faces.

Generally, this is the arrangement adopted to make the "joint" where a rod has to work through a cover or plate on one side of which the pressure is greater than on the other, whether that pressure be of steam, water, or air.

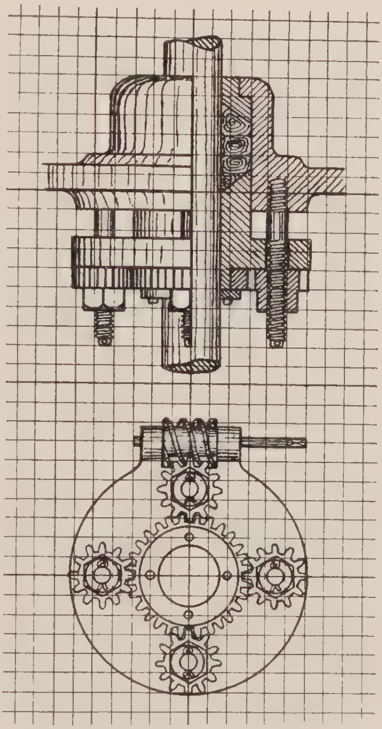
In the case of the propeller shaft passing through the stern of the ship, in Fig. 37, a tube called the "stern tube" is fixed into the framework of the stern of the ship, this stern tube acting as a bearing to support the weight of the shaft and the propeller, and the water is prevented from passing between the shaft and the tube by means of one of these stuffing boxes and glands, arranged at its inner end, the packing used in this case being "gasket" or soft woven hemp rope, generally of square section, and soaked in tallow.

Naturally it is of the utmost importance that the gland be forced forward evenly on all sides. In small glands, where there are only two studs and two nuts to screw up, as in Fig. 103, this is easily done by giving exactly the same number of turns to each nut, a little at a time, first on one and then on the other, the gland "canting" slightly as each nut is screwed forward.

In large glands, where four or more studs and nuts are used, this would be by no means an easy matter, so each of the nuts is made into a small cog-wheel and a large toothed ring is fitted on to the face of the gland, as shown in Figs. 104 and 105, concentric with the rod, and free to revolve.

The teeth on this ring engage with the teeth of each of the nuts, so it is evident that by turning any one of these nuts the ring will be made to revolve, and will in turn cause all the other nuts to revolve to exactly the same extent as the one we screwed up with the spanner, and the gland will be forced forward evenly. It would often be extremely awkward to get at the back nuts with a spanner, especially if the engines were at work, so this arrangement is very convenient.

In the case of the piston-rod glands, which frequently require screwing up when the engines are going, it is usual in large engines to fit a screw arrangement, acting on the teeth of one of the small wheels forming a nut, by means of which screw the gland can conveniently be tightened from the front of the engine, as shown in Fig. 105.



FIGS. 104 105

The packing used depends on the work the stuffing box has to do. As we have seen, gasket made of hemp is used for the "stern gland," as it is called. This answers well in this case, the pressure being but small, due as it is to the depth of the stern tube below the surface of the water; in a big ship this would be a matter of 18 or 20 ft., giving only 9 or 10 lbs. pressure per square inch; also there is no heat to contend with.

For higher pressures, where water is being dealt with, as in the case of pumps, a different sort of packing is required.

In the Navy, what is known as "elastic core packing," is generally used for the stuffing boxes of all pumps. This consists of a core of india-rubber, round which canvas is tightly coiled, the india-rubber core giving the necessary elasticity. This packing also works fairly well for low pressures of steam, but the india-rubber will not stand the heat when high pressures are used.

For high-pressure steam, the most usual type of packing is made of yarns of "asbestos" woven together into a rope. This stands very well, as the asbestos is unaffected either by the heat or by the oil used for lubricating the rod, which in the case of the elastic core packing gradually rots away the india-rubber of the core.

METALLIC PACKING

With the very high pressures of steam now employed, "metallic packing" is almost invariably used for piston and slide rod glands, where these are of any size.

This packing consists of "segments" of white metal, three of which segments are made to form a ring round the rod, squeezed in against the rod by some means or other, the ends of the segments not quite butting against each other when in place, thus allowing of their being closed in against the rod when the packing wears away, to maintain a steam-tight joint.

One of the most usual types of metallic packing, known as "combination metallic packing," consists of alternate rings of white metal built up of these segments, and of gun metal, the top and bottom faces of the gun-metal rings being sloped, as are the faces of the neck bush and gland, the faces of the white metal sections being suitably sloped to meet these. First a section of white metal is put into the stuffing box against the neck bush; then a gun-metal ring, then another section of white metal, and so on, until the stuffing box is full, when the gland is put in place and screwed up against the face of the last section. As will be seen from the sketch in Fig. 106 the effect of screwing up the gland is to force the gun-metal rings outward against the sides of the stuffing box, and the white metal inward against the rod.

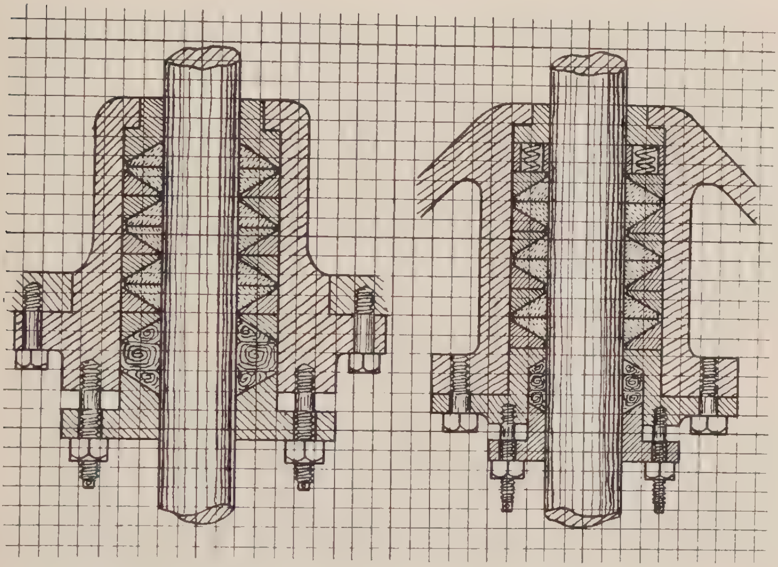


FIG. 106 FIG. 107

Generally the gland is not made adjustable, as in the case of a stuffing box using "soft" packing, but the necessary pressure between the gun-metal rings and the white-metal ones to force the white metal forward against the rod is obtained by means of a number of small springs fitted in the last gun-metal section, the face of the neck bush being flat for these springs to act against.

Only the white-metal sections actually bear against the rod, the gun-metal rings merely serving to force the white metal forward, and not themselves touching the rod at all.

In addition to the metallic packing, it is usual to fit a few "turns" of soft packing in order to stop any small quantity of steam which may "weep" past the metallic packing.

This soft packing is fitted either in the same stuffing box as the metallic packing, or else in an entirely separate stuffing box with a separate gland. In the first case, the gland is made adjustable, with its inside face sloped, and the springs are dispensed with, the elasticity of the soft packing pressed forward by the gland being sufficient to bring the wedge action of the metallic packing into play.

For large stuffing boxes the second plan is the more usual, the fixed gland holding the metallic packing in place being made to act as the secondary stuffing box for the soft packing. The arrangements of these two forms of stuffing box using metallic packing are shown in Figs. 106 and 107.

COCKS AND VALVES

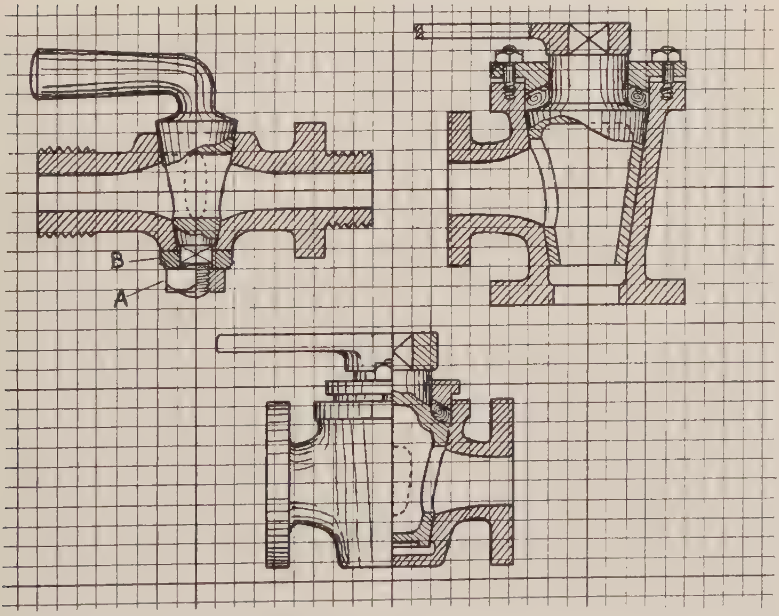
In our single-acting cylinder in Fig. 51 we "controlled" the supply of steam to and exhaust from the cylinder by means of cocks, which we said were like water taps.

The principle on which all cocks are made is very simple—a round "plug" with a hole through it, fitting in a hollow "shell," a hole being bored through both sides of the shell to correspond with the hole in the plug. If the plug be turned into such a position that the hole in it is across the shell, the holes in the shell will be blocked by the solid sides of the plug, while if the plug be turned so that the hole is in line with the holes in the shell, the steam or water will have a free passage from one side of the shell to the other.

If the plug were made cylindrical, working in a cylindrical shell, the least wear would cause leakage, so the plug is made "taper," the shell being bored out taper to suit it.

As wear takes place the plug can be forced a little further into the shell, when it will again fit steam-tight.

In small cocks, such as the one shown in Fig. 108, the plug is kept tight in the shell by means of the nut A on a screwed continuation of the plug below the



FIGS. 108, 109, 110

shell; a "washer" B is fitted on a square on the end of the plug, and so turns with the plug, thus preventing the nut from being "slacked back" by its friction against the end of the shell when the cock is opened or closed.

In larger-sized cocks this arrangement would be very heavy and cumbersome, so another plan is adopted, as shown in Fig. 109, where the bottom of the shell is made solid and the plug is kept forced home in the shell by means of a shallow stuffing box in the upper part of the shell, the packing bearing directly on the top of the plug.

This arrangement not only keeps the plug in its place, but also prevents any leakage past the top of the plug.

Such cocks as those shown in Figs. 108 and 109 are known as "straight-way" cocks, the direction of flow of the steam or water not being changed. Fig. 110 shows a "right-angle" cock, where the steam or water passes into the inside of the plug and out again through a hole in the bottom instead of straight ahead.

Cocks are very convenient in some ways, as they can be shut off almost instantaneously, but when of any considerable size they need a good deal of force to move them, and they are very subject to leaking. Consequently they are but little used in engineering work except for such small things as the "drain cocks" fitted at the bottoms of cylinders, in steam pipes, and such like, to drain out any water which may have collected there, and for small pipes generally.

They are invariably made of gun metal for whatever purpose they may be intended, whether for steam or water.

VALVES

There are many kinds of valves, used for many different purposes, but the general object of all valves, as of cocks, is to control the passage of a fluid from one space to another, and where large quantities have to be dealt with, valves are used in preference to cocks.

We have seen what a slide valve is. It consists essentially of a metal plate fitting against, and sliding backward and forward on, another metal surface in which is an opening or port, through which steam or water is allowed to flow or prevented from flowing, according as the slide valve uncovers or covers the port as it slides back and forth across the opening.

Other than the slide valve, valves may broadly be divided into two general classes—

(1) Those which can be opened and closed at will by turning a wheel or handle, or moving a lever, allowing steam or water to flow past the valve, or preventing its flow by closing the passage.

(2) Those which open and close "automatically," allowing the steam or water to pass according as the pressure on the one side or the other be the greater, but which cannot be controlled by hand.

Valves of the former of these two classes are used for controlling the flow of steam from the boiler to the engines, for regulating or shutting off the supply of steam to any particular engine, or for regulating the amount of water flowing through a pipe.

Valves of the latter class are used in pumps, where water is forced from one space, at a high pressure, into another space in which the pressure is not so high, the higher pressure on the one side of the valve forcing it up off its seating, and so passing; when the pressure acting on the top of the valve is the greater, it presses the valve down again on the seating, and the water is unable to flow back again.

THE STOP VALVE

Let us first consider the first class.

Suppose we wish to stop the flow of steam or water from an open end of a round pipe. If we take a conical plug of wood or metal and force it against the end of the pipe, and fix it so that it cannot move, say, by putting a piece of wood or metal between it and some fixed object such as a wall, as shown in Fig. 111, then the passage of the steam or water through the pipe would be stopped.

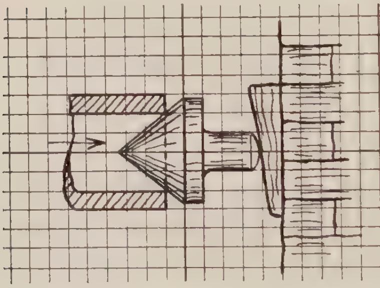


FIG. 111

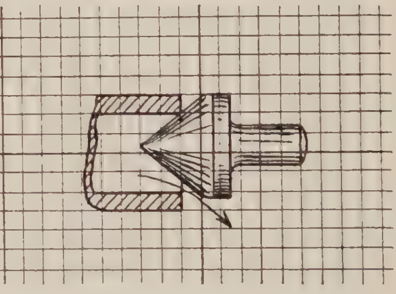


FIG. 112

If we remove the strain from behind the plug, the pressure in the pipe will force the plug away, and the steam or water will again flow out of the end of the pipe.

Then this plug would be called a valve, and the plug, the end of the pipe, and whatever is used to keep the plug in place, would together form a "stop valve."

The object of making the plug or valve conical is that it shall "centre" itself in the hole in the end of the pipe.

If the end of the conical valve were put in the end of the pipe, but not in the centre, then one side of the valve would "take against" the side of the pipe before the other did, leaving an opening, as shown in Fig. 112. But the valve being conical, that side would act as a wedge when it was forced forward, and would drive the valve over until the other side also bore against the edge of the hole, effectually stopping the passage all round.

So the actual valve in a stop valve is always made conical, the inside edge of the hole against which the valve bears being "bevelled" away to the same angle as the cone of the valve, to form a "seating," as the sharp edge of the pipe would soon cut into the valve.

In actual practice, the stop valve is made separate from the pipe and supplied with two flanges (A and B in Fig. 113), to which the pipes leading the steam or water to the valve and away from it, having similar flanges on their ends, are secured by means of bolts.

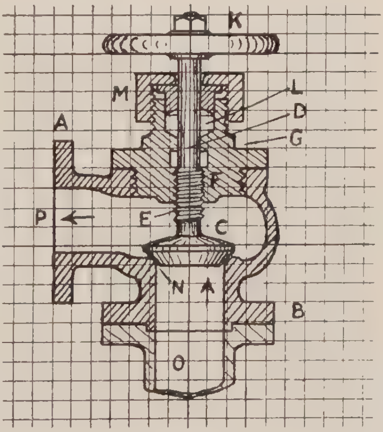


FIG. 113

The simplest form of stop valve, used for quite small work, such as controlling the steam supply from the boiler to the engines in a steam boat, or for small "auxiliary" engines such as feed pumps, is shown in Fig. 113, where C, the valve, is made in one piece with the spindle D, and pressed against the seating N to shut off the steam which comes through the pipe O *underneath* the valve.

Above the seating, the "valve box" widens out to allow the steam to pass round the sides of the valve, and the steam, when it has passed from the valve, escapes from the valve box through the pipe P. The top of the valve box is closed by a cover G, which is screwed into the box itself. Through this cover the valve spindle D passes, so as to be accessible from the outside, to press the valve on to its seating, to stop the supply of steam.

In order to be able to hold the valve firmly on its seating against the pressure of the steam beneath it and tending to force it off the seating, the spindle D has a screw thread E cut upon it which engages in a suitable nut formed in the cover at F. On the outside end of the spindle D is fixed a "hand wheel" K, by means of which the spindle can be turned, to force the valve tightly on to its seating to shut off the steam, or to draw it back off the seating to allow the steam to pass. To prevent the steam from leaking out where the valve spindle passes through the cover, a stuffing box L is arranged in the cover, the nut M acting as a gland and gland studs combined to keep the packing in the stuffing box compressed and the joint tight.

This is the general idea on which all stop valves work, but in a large stop valve there would be many points in which this particular arrangement would not be suitable.

The first of these points is—as the valve forms part of the spindle, and is forced forward on to its seating by screwing the spindle through the nut in the cover by turning the hand wheel, the valve will turn with the spindle and will "grind" against the seating as it is screwed hard home.

This would cause both valve and seating to wear away, and make it almost impossible to keep the valve tight. Consequently the valve is made separate from the spindle, so that it shall not turn as the spindle is screwed round to close or open the valve. Naturally, the valve must be connected to the spindle so that when the spindle is screwed back the valve will move back with it, even without the help of the steam acting underneath it and forcing it off its seating. This arrangement is shown in Fig. 114. When the valve and spindle were made in one piece, the spindle kept the valve central, so that it always came fair on to the seating; but with the valve separate from the spindle this would not be the case; so the valve has to be arranged to keep itself central with the seating, independent of the spindle. To do this, the valve is provided on its under side with "webs" or "wings," generally either three or four in number, ar-

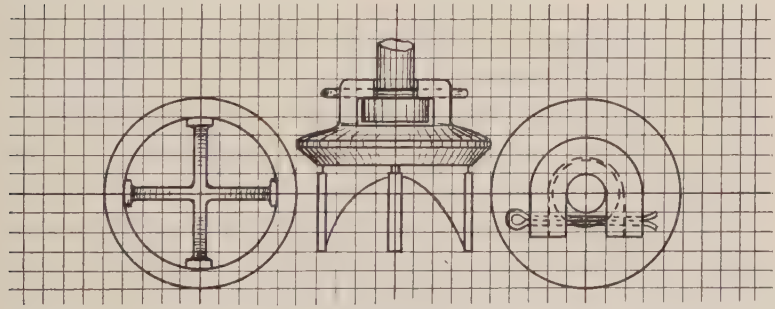


FIG. 114

ranged as shown in Fig. 114, which fit in the part of the valve box beneath the seating, and so keep the valve central. These webs must of course be quite free—in fact, they must be a very loose fit—to allow the conical valve to centre itself properly on its seating.

The next point of difference between the small valve shown in Fig. 113 and the larger valve we are now considering lies in the method of screwing the spindle in and out to close and open the valve.

In Fig. 113 this was done by the screw thread on the spindle working through the nut made in the inside of the cover and on the steam side of the stuffing box. It is obvious that it would be impossible to lubricate this screw, as the oil could not be got on to the thread owing to the pressure of the steam forcing it back. In the large valve this would be a serious defect, as the thread on the spindle and in the nut would very soon wear away.

So instead of making the nut in the cover on the inside, where it cannot be got at, it is made in a separate piece called the "bridge," which is fixed on to the cover, as shown at A in Fig. 115, the spindle being screwed to suit this new position of the nut. Thus the screw is always visible, and can be lubricated without difficulty.

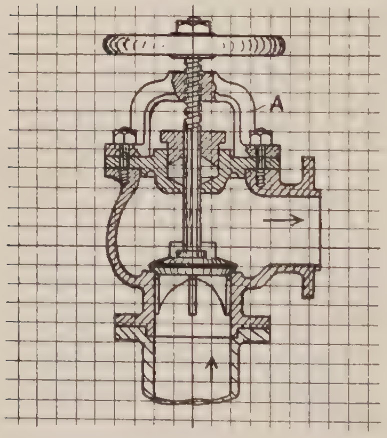


FIG. 115

The arrangement of stuffing box shown in Fig. 113, though very simple, and suitable for such small valves, would be heavy and expensive in a large one, so an ordinary stuffing box with gland and gland studs is used, made in the cover and below the thread on the spindle, as shown in Fig. 115.

The cover in the large valve, instead of being screwed into the top of the valve box, is secured to it by means of studs and nuts or bolts in the usual way.

In both of the stop valves we have been considering, the direction of flow of the steam from the stop valve is at right angles to that at which it enters the valve.

THE STRAIGHT-WAY STOP VALVE

Where it is necessary to keep the flow of the steam in the same straight line, as, for instance, for shutting off the steam from one part of a straight line of steam pipe, a different form of stop valve, called a "straight-way" stop valve, is used. This is in all essential points the same as those we have been considering, the steam, being led underneath the valve, tending to force it off its seat, on to which it is held by means of a screw. This form is shown in Fig. 116.

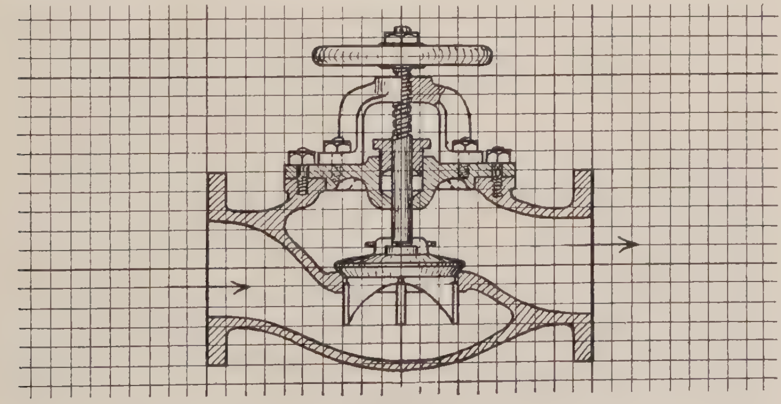


FIG. 116

THE SELF-ACTING STOP VALVE

If, as is almost invariably the case in warships, there are a number of boilers all supplying steam to the engines through the same main steam pipe, it is obvious that should an accident occur to any one of these boilers, such as its being pierced by a shot, not only will the contents of that boiler escape and cause damage, but the steam from all the other boilers also will escape through the hole, rushing back through the steam pipe and stop valve into the damaged boiler instead of going on to the engines. So an accident to one boiler would mean the complete disablement of the ship, as there would be no steam available to drive the engines.

To prevent this and keep the damage as local as possible, the stop valves on the boilers are made "self-acting," that is, they will automatically close themselves if the pressure beneath them be suddenly reduced.

This is done by making the valve independent of the screw, which can then only be used to keep the valve shut, or to regulate its amount of opening, but not to open the valve, which is done by the pressure of the steam in the boiler forcing it off its seating when the screwed spindle is worked back by means of the hand-wheel.

Then, should an accident occur to the boiler, and the pressure beneath the valve suddenly drop, the pressure in the steam pipe acting on the top of the valve, being then the greater, would drive it down on to its seating and so shut it off, thus keeping the damage to the one boiler only. This valve would be a "non-return" valve.

The most obvious way of getting this result would be to do away with the arrangement on the back of the valve shown in Fig. 114, by which the valve is connected to the spindle so as to be able to lift it off its seating, merely allowing the end of the spindle to act on the back of the valve to close it.

There is, however, one very decided practical objection to this simple arrangement.

Before starting an engine it is necessary to "warm it through," so that the full heat of the steam shall not suddenly be brought to bear on the engine, as this would cause unequal expansion of the metal of the cylinders and other parts in contact with the steam, with the probable result that they would crack. Consequently the heat has to be applied gradually.

When "raising steam" in the boiler it is usual to open the stop valve to allow the air and vapour from the boiler, which gradually becomes hotter under the action of the fire, to pass through the engines until the pressure in the boiler begins to rise, when the steam supply to the engine is shut off, except just sufficient to continue the "warming through."

It is obvious that at first there is no excess of pressure in the boiler to lift the valve off its seating to get this result, so means must be provided to lift the valve independently of this pressure.

To do this the valve spindle itself (in this case made in one piece with the valve) is not screwed, the force to close the valve being applied to the valve by means of a separate screw, worked by a hand-wheel.

The arrangement of a self-acting stop valve is shown in Fig. 117, where the valve spindle passes through the hollow screw worked through the nut in the bridge by means of the hand-wheel, the end of the screw acting against a shoulder on the valve spindle to close the valve.

It will be seen that when the screw is worked back, the valve is free to open or close, according as the pressure beneath or above it be the greater, and it can

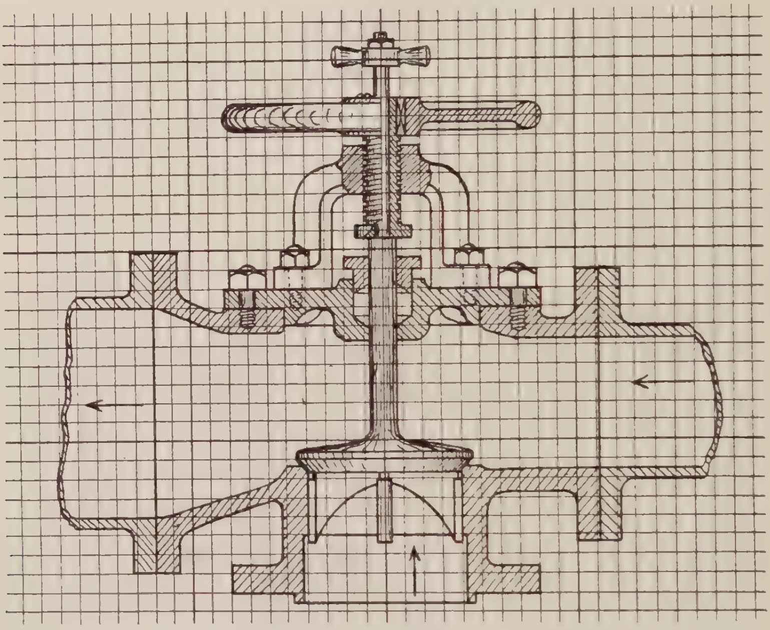


FIG. 117

be pulled back off the seating by means of the small handle on the end of the spindle when there is no pressure in the boiler to help to lift it.

Also, it will be seen that even though the spindle be in one with the valve, the valve will not be turned round on the seating by the working of the screw in freeing or closing.

In all valves of this type, whether self-acting or not, we must make certain that they will allow as much steam or water to pass the valve as can pass through the pipe on which they are fitted, that is, the area of the passage past the valve must be the same as the area of the passage underneath or beyond it. The area of the valve seating is

πr^2 or 3.1416 × the square of the radius of the seat.

To get this same area past the valve, we see that it must lift off its seating to such an extent that the "lift" multiplied by the circumference of the valve shall equal the area of the valve. If L be the lift, then

$$\pi r^2 = 2\pi r \times \mathrm{L},$$
$$\therefore \mathrm{L} = \frac{\pi r^2}{2\pi r} = \frac{r}{2}$$

that is, the lift of the valve must be equal to half the radius, or a quarter of the diameter of the valve.

NON-RETURN VALVES

The object of non-return valves is to allow of the flow of the steam or water past the valve in one direction while preventing its flowing back whence it came.

When the pressure beneath the valve is greater than the pressure above it, the valve will lift, allowing the steam or water to flow past, but when the pressure above the valve is the greater the valve closes, and prevents the flow of the steam or water back again.

The most familiar application of the non-return valve is in the ordinary pump, known as a "lift pump," used for pumping water out of a well. In these lift pumps, the most usual type of non-return valve is that known as a "clack valve," which is really nothing more nor less than a shutter or door without a latch.

If we push against the door from the one side, it opens and allows us to pass, but if we push from the other side, the door shuts and we cannot get through.

So an ordinary lift pump consists of a cylinder in which works a piston, known as a "bucket," in which is arranged a clack valve, which allows of the passage of the water from beneath the bucket to above it, but not back again, as shown in Fig. 118.

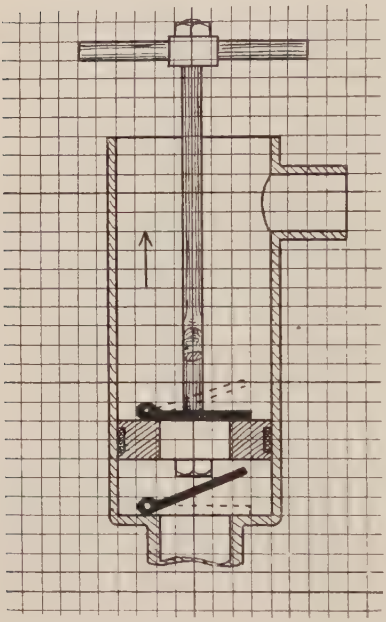


FIG. 118

At the bottom of this cylinder is another similar clack valve working on the end of the pipe leading from the well as a seating.

On the down stroke of the bucket the pressure caused by pushing it down causes the lower clack valve to close and that in the bucket to open, allowing the water in the cylinder to pass from beneath the bucket to above it, ready to be pumped out through the spout on the next up stroke.

Then, on the up stroke, the valve in the bucket closes as the pressure beneath it is removed, and the water is lifted up by the rising bucket, and flows out through the spout, and at the same time, the bucket moving up tends to create a vacuum beneath it in the cylinder.

"Nature abhors a vacuum," and so tries to fill up the empty cylinder. The pressure of the atmosphere on the surface of the water in the well forces the water up the pipe, lifts the lower or "foot valve," and the water fills the cylinder—that is, provided the height of the pump above the surface of the water be less than about 28 ft., the height of the column of water which the pressure of the atmosphere will support being about 32 ft., which corresponds to the 30 in. of mercury in the barometer.

From this we see that when we talk of a pump "sucking" up the water we are only partly right, as the pump does not suck up the water at all, but merely creates a vacuum into which the pressure of the atmosphere forces the water, the actual lifting of the water being done by the pressure of the atmosphere.

Non-return valves of this type are but seldom met with in engineering work, as the water only being able to escape on the one side of the valve, the other side being hinged to the seating, the lift necessary to give free passage to the water on the one side of the valve only would need to be proportionately increased.

Formerly the non-return valves used for dealing with water were almost invariably made of india-rubber, but this material wears out rather quickly and is very expensive, and also is very subject to deterioration from the action of grease or oil in the water. Consequently metal valves have now almost entirely superseded the rubber ones.

Conical valves, practically the same as the self-acting stop valve, are much used, the only difference being that the valve spindle is dispensed with, and instead of a screw passing through the cover to hold the valve down, the cover itself is arranged so as to prevent the valve from lifting too much. Another very usual form of non-return valve is shown in Fig. 119.

This consists of a metal disc, sliding up and down on a stud fixed in the centre of the valve seating, which disc, when down on the seating, prevents water from flowing downward, but if the pressure beneath it be in excess of the pressure above it, the disc lifts bodily upward off the seating, allowing free passage for the water. A "guard" is fixed on the top end of the stud at a suitable height above the seating, to prevent the valve from lifting too far.

Frequently, instead of one thick metal disc, as shown in Fig. 119, a number (generally three) of thin discs are used, a few small holes being made in the two lower discs to allow a little water to get between the discs to deaden the shock when the valve comes down on the seating.

These thin discs are generally made of a special sort of bronze, which stands the "hammering" of the valve on its seating very well, and seldom cracks.

The arrangement of this valve is shown in Fig. 120.

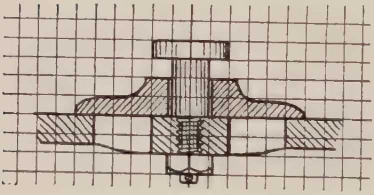


FIG. 119

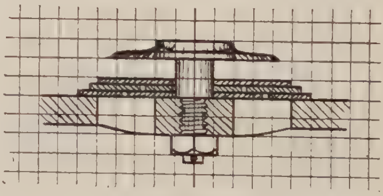


FIG. 120

CHAPTER VI

THE CONDENSING ENGINE

NOW that we understand the means whereby the power obtained by the boiling of water in a closed vessel or "boiler" can be used for propelling our ship, and know something generally of the details of the essential parts of the engine, we are in a position to go further into the idea of the engine itself, and to see how we can use our power more effectively.

Naturally the point we must aim at, especially in a ship, is to get the largest possible amount of power out of the smallest possible amount of fuel, not only on the score of economy, but also that the ship may be able to steam the greatest possible distance with the amount of fuel she can conveniently carry.

In the steam engine, at the point to which we have brought it, we still have the 15 lbs. pressure of the atmosphere acting against the piston, and so reducing the power of the engine. Obviously, if this can be removed, we get a great deal more power for the same expenditure of steam and of fuel, and so at less cost for the power obtained.

CONDENSATION OF STEAM

At page 106 we said that a "plentiful supply of water" was needed in order to enable us to remove even the 15 lbs. back pressure of the atmosphere from the side of the piston toward which it is travelling, by converting the steam at atmospheric pressure (after it has done its work in the engine) back again into water, giving a reduction in volume at the rate of 1 cubic foot of steam to 1 cubic inch of water, leaving the remainder of the cubic foot of space entirely free from pressure.

We have seen that this "condensation" or conversion of steam back again into water is done by taking away some of its heat, as steam cannot exist in the form of steam at a low temperature, but turns back into water.

So, to remove the heat from the steam after it has done its work in the engine, cold water is used.

THE ATMOSPHERIC ENGINE

The very first engines using steam were not really "steam" engines, but were, as their name implied, "atmospheric" engines, the steam serving, not to give the power, but merely as a means of obtaining a vacuum, the actual power being derived from the pressure of the atmosphere.

The arrangement first tried, which was employed for working pumps for removing the water from mines, was to a certain extent similar to our single-acting engine, worked by means of cocks, as shown in Fig. 51, only in this case, instead of the weight being used to send the piston down to the bottom of the cylinder, it was used to pull it up to the top, as shown in Fig. 121.

From the bottom of the cylinder a pipe was led to a copper pot or boiler, partly full of water, underneath which was a fire. This boiler, which worked at atmospheric pressure or even below it, was provided with a "safety valve" consisting merely of a plate or stopper, covering the end of an open pipe from the steam space of the boiler, the plate lifting and allowing the steam to escape when the pressure in the boiler exceeded atmospheric pressure.

On the piston being pulled up by the action of the weight of the pump rod at the other end of the "beam," steam was drawn from the boiler into the cylinder to fill the space below the piston. The cock on this steam pipe was then closed and a spray of cold water was "injected" into the cylinder; this condensed the steam and made a vacuum under the piston when the 15 lbs. pressure of the atmosphere forced the piston down. When it reached the bottom of its stroke, the water "jet" was shut off, and the piston being held down, the "injection" water and condensed steam were allowed to run out through a drain cock.

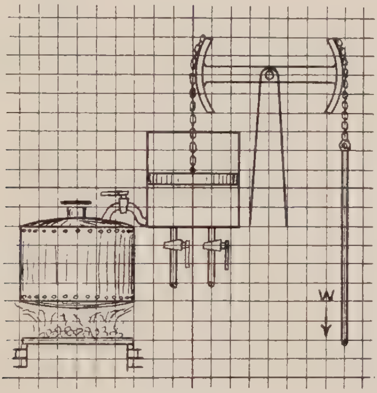


FIG. 121

THE JET CONDENSER

This was a very uneconomical arrangement, as the injection water not only condensed the steam, but also cooled the cylinder, with the result that on again letting in steam, much of this steam was condensed by the cold metal of the cylinder and was wasted before any became available for allowing the piston to rise when it was released.

So the steam was led from the cylinder into a separate vessel called a "condenser" and there condensed by the water jet, thus saving the alternate cooling and consequent reheating of the cylinder.

This is practically the arrangement now used for condensing the exhaust steam from the engines so as to remove the atmospheric pressure from the front of the piston.

THE AIR PUMP

Naturally the injection water and the condensed steam would soon fill up the condenser, so a pump has to be used to remove this water. This pump is known as the "air-pump," which seems rather an absurd name for a pump which appears to be provided to deal with water.

The name is not really as unsuitable as it seems, though with the arrangement of condenser now most generally used for land work and practically always for ship work, it no longer applies as much as it formerly did.

Water, we know, contains a large amount of air "in solution." (Sweetened tea is tea with sugar "dissolved" or "in solution" in it.)

This air dissolved in the water is what fishes breathe; a fish will as surely die in pure distilled water, which contains no air in solution, or in water which has been boiled, and so the air driven out from it, as if removed from the water altogether.

The "singing" of the kettle before it boils is partly caused by the liberation of the air which was in solution in the water, and which can be seen forming itself into small bubbles against the sides and bottom of the kettle while the water is still comparatively cold.

Well, the injection water contained a large amount of air in solution, which, under the very much reduced pressure in the condenser, and also owing to the heat of the steam being condensed, was liberated, and so very soon spoiled the vacuum. The air-pump had to remove this air as well as the water, hence its name.

Generally speaking, the air-pump is practically an ordinary lift pump of the type shown in Fig. 118, but arranged so that the "foot valve," as the lower valve is called, shall be below the level of the bottom of the condenser, so that the water shall flow down to the pump instead of having to be "lifted."

It is usual to fit another valve or set of valves at the top of the pump cylinder or "barrel" to assist the others and to obtain a better vacuum.

In any but very small air-pumps, instead of having a single foot valve and a single bucket valve, a number of smaller valves are used, the lift for these smaller valves naturally being much less than would be required for the single larger one, and consequently the valves work much more quietly and last much longer.

The general arrangement of a "jet condenser" with its air-pump is shown in Fig. 122, where it will be seen that instead of the injection water being in one single jet, it is brought into the condensing chamber through a pipe with a number of small holes in it, which breaks the jet into a spray, giving the water a better chance of acting on the inrushing exhaust steam, to condense it.

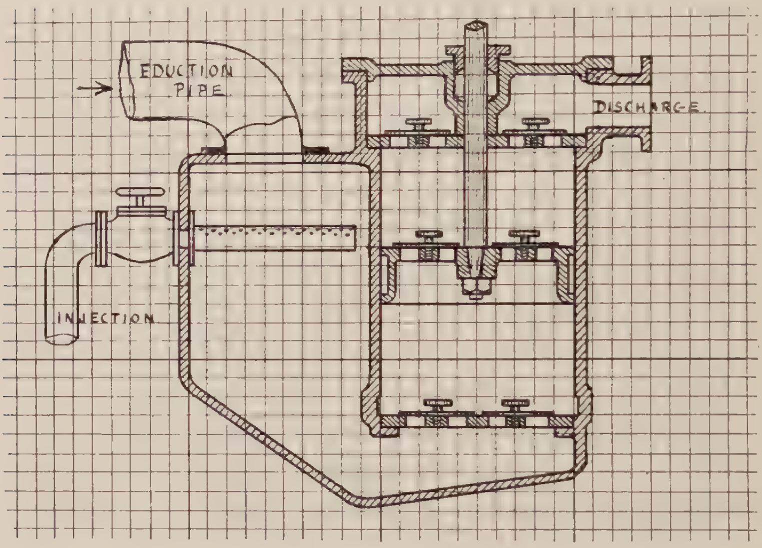


FIG. 122

THE SURFACE CONDENSER

Though excellent results are obtained from the jet condenser and a very good vacuum kept up, there are serious objections to its use on board ship.

Sea-water contains a large amount of solid matter in solution, to the extent of about one thirty-second part of its weight, in fact. That is, if we put 32 lbs. weight of sea-water into a vessel and boiled all the water away, there would remain 1 lb. weight of solid matter in the vessel.

This solid matter consists of a mixture of various "salts," the chief of which is the common salt used for household purposes, or sodium chloride, the others being salts of magnesium and lime.

If we were to "feed" our boiler with sea-water, as the steam was generated and used in the engines, and more sea-water pumped into the boiler to take its place, this solid matter would be left behind and would very soon cause trouble, unless means were adopted to get rid of it.

So it is advisable, if not absolutely necessary, to feed the boiler with fresh water, which does not contain solid matter. It would be impossible to carry sufficient fresh water to last for any length of time, and as the steam on leaving the engines is really pure fresh water, why not use that for feeding the boilers instead of salt water?

With the jet condenser which we have been considering, the sea-water used for condensing the steam mixes with the fresh water obtained by the condensation of the exhaust steam, and so spoils it for boiler feed purposes.

As all we have to do to condense the steam is to carry away sufficient of its heat to cause it to turn back into water, why not do this without letting the condensing water and the steam mix, by bringing the steam into contact with a surface kept cold by a stream of sea-water on the other side of it?

Naturally a large surface is required to enable the heat of the steam to be got rid of quickly enough, and this large surface is best obtained by means of tubes of comparatively small diameter enclosed in a suitable casing into which the exhaust steam passes, the tubes being kept cold by sea-water pumped through them, the steam surrounding the tubes being condensed by contact with their cold surfaces.

Thus the steam is condensed without in any way mixing with the sea-water used for carrying away the heat, the resulting water being pure and free from all solid matter, and in every way suitable to be used over again in the boiler.

Naturally, as in the case of the jet condenser, an air-pump is required to remove this water from the condenser, but this pump does not need to be so large as for the jet condenser as it only has to deal with the water from the condensed steam, there being no injection water ; also the amount of air which it has to remove from the condenser is very much less, being only what happens to leak in through defective packing or joints and leaky glands, none being brought in as was done by the injection water, having air in solution, in the case of the jet condenser.

With the jet condenser, the air-pump discharged the water taken from the condenser overboard, only sufficient being taken from it to feed the boilers ; but with the surface condenser, all the resulting water is discharged by the air-pump through a pipe to a tank called a "feed tank."

So the same water will be used over and over again, being first converted into steam in the boiler, then doing its work in the engines, then being turned back into water in the condenser, from which it is removed by the air-pump and discharged into the feed tank, ready to be pumped back into the boiler by the feed pump for its next round of duty, only sufficient fresh water being carried or "distilled" to make up for wastage through leaks of water or steam in the engines or elsewhere.

The most usual type of surface condenser, such as shown in Fig. 123, consists of a "casing" or "barrel," which, in the Navy, is generally either a gun-metal casting or else is built up out of sheet brass, generally of cylindrical shape, closed at the ends by flat plates called "tube plates" through holes in which the thin "condenser tubes" pass, reaching from tube plate to tube plate through the length of the casing, the joints where they pass through the tube plates being made water-tight by some means, generally a screwed gland and packing, shown in Fig. 124.

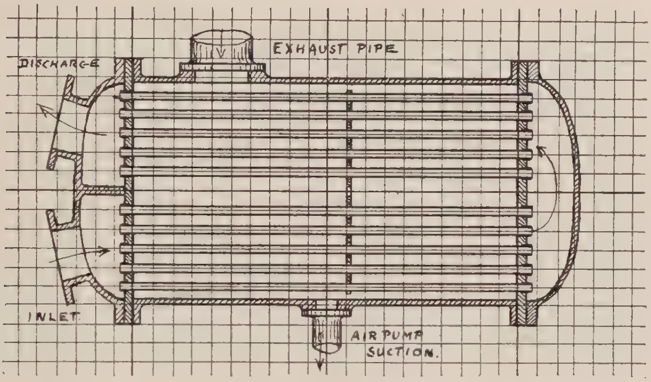


FIG. 123

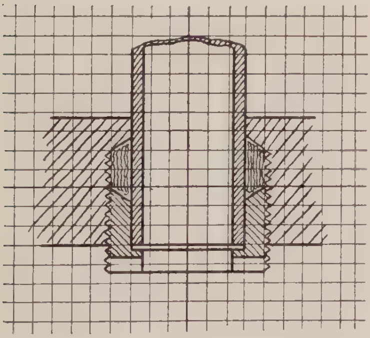


FIG. 124

The exhaust steam is led from the engines into the condenser casing through a pipe known as the "eduction pipe," or "exhaust pipe."

In order to be able to pump the sea-water through all the condenser tubes to keep them cold, a large cover is fitted on to either end of the condenser, outside the tube plate, a space being left between the ends of the tubes and the inside of the cover, so that when the sea-water is forced from the sea by means of a suitable pump known as a "circulating pump" into one of these covers, it will flow through the tubes into the other cover, whence it is led overboard through the "circulating discharge pipe."

As the "circulating water," as it is called, can only collect the heat from the inner surfaces of the tubes comparatively slowly, it is usual to make it pass twice through the tubes. This is done by having both "inlet" and "discharge" pipes leading from the same cover, the former to the bottom and the latter from the top, a "diaphragm plate" on the inside of the cover being arranged to fit against the face of the tube plate, dividing the space between the cover and the tube plate into two separate compartments, with half the tubes opening into each.

Then if the circulating water be pumped into the lower compartment of the cover, it will flow through the lower half of the tubes into the other cover and back again into the upper compartment of the first cover through the upper half of the tubes, and so overboard through the discharge pipe.

From the bottom of the condenser casing a pipe is led to the bottom of the air-pump, which, as in the case of the jet condenser, is arranged to be below the bottom of the condenser for the same reasons.

Fig. 123 shows a condenser of this type with the tubes arranged horizontally. They are sometimes made with the tubes arranged vertically, but the general idea in that case is precisely the same, except that with the vertical condenser, the exhaust steam is generally led by the eduction pipe into the top cover, and it passes through the tubes instead of round them, the water passing inside the casing and round the tubes.

This arrangement, though giving slightly less cooling surface than when the steam passed round the tubes, has two good points, for the water being next the casing instead of the steam, keeps the casing cold, which is better for the comfort of the engine-room. Also, the grease which is brought into the condenser with the steam, collected from the oil used for the lubrication of the internal parts and that used on the piston and slide rods, is deposited inside the tubes, whence it can easily be removed by means of a brush. Where the steam passes round the tubes this grease is deposited on their outsides, when the only way of removing it is by filling the condenser with a solution of soda or potash, and then boiling, which dissolves the grease.

In the horizontal condenser, the tubes, being thin and of considerable length, tend to "sag" or bend downward in the middle, owing to their weight and the weight of the water inside them. Some of the tubes would be certain to sag more than others, and so they would touch each other at some point between the tube plates. As there is always more or less vibration when the engines are at work, the tubes would rub against each other at these points and would in time wear themselves into holes, which would be very bad, as not only would the vacuum be reduced, but the salt water would be drawn by the vacuum through the holes and would mix with the condensed steam, with the result that solid matter would find its way into the boilers and cause trouble.

To prevent this, it is necessary to support the tubes between the tube plates, which is done by diaphragm plates fitted inside the casing, with holes for each tube to pass through, thus giving the necessary support.

If the tubes are comparatively short, say 10 ft., only one diaphragm plate is fitted, but if long, two or more are necessary. The diaphragm plates are not arranged exactly at equal distances apart, for reasons which need not be considered here.

In the vertical condenser, this point of supporting the tubes does not come in, but there is another difficulty which has to be met. The weight of the tube itself, acting downward, will cause the tube to slip down through the packing gland, unless means be adopted to prevent it so doing.

This is easily and cheaply done by the arrangement shown in Fig. 124, of the screwed gland and packing used for keeping the joint between the tube and the tube plate water-tight, the gland in this case being provided with a "shoulder," as shown in the sketch, against which the end of the tube bears at its lower end, which effectually prevents it from dropping.

THE CIRCULATING PUMP

We have seen that it is necessary to pump cold sea-water through the condenser to keep the tubes cool, so that the steam shall be condensed by contact with their surfaces.

If the amount of sea-water pumped through were small, the large amount of heat which has to be removed in order to condense the steam would soon raise the temperature of the circulating water to such an extent that the cooling surface would no longer be efficient, and the vacuum would suffer.

So it is necessary that a large volume of water be pumped through. As this water is drawn by the "circulating pump" through an inlet pipe leading through the bottom of the ship, and after passing through the condenser is discharged through the side again (generally below water level), we see that but very little power is required to cause the water to circulate, though the volume is large, as we have practically no "lift" to contend with, the only resistance being the friction of the water against the sides of the tubes, pipes, and condenser, as it flows through them.

Pumps of the type shown in Fig. 118 are, we have seen, capable of lifting water from a depth of about 30 ft., and can be made to "force" it to almost any height, but they can only deliver one pump barrel full of water at each stroke.

So if such a pump were used as a circulating pump, it would have to be made very large in order to deliver the necessary volume of water, unless driven very fast, which would be bad for the valves. Also, it would be rather like driving a tin tack with a sledge hammer, using a pump capable of lifting water through a great height, to do this work where the lift is so very small.

Consequently a different kind of pump, known as "centrifugal," is almost invariably used as a circulating pump.

These centrifugal pumps, though not suitable for lifting water through any considerable height, are capable of delivering a very large volume of water where, as in this case, the lift is small.

If we tie a string to a stone, and swing it rapidly round and round, the stone tries to fly away from our hand holding the end of the string, pulling more and more strongly against the string holding it in to the centre round which it is revolving (our hand, in this case) as the speed of revolution increases.

This force, tending to cause the stone to fly outward, is known as "centrifugal force," and is the force utilised in the centrifugal pump, the water taking the place of the stone trying to fly away from the centre.

The arrangement used is shown in its simplest form in Fig. 125, where a circular "fan," or "impeller" A, mounted on a shaft B, is made to revolve by means of the shaft inside the casing C.

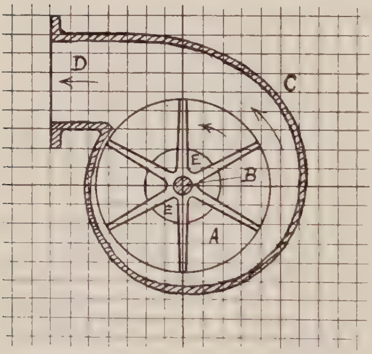


FIG. 125

The impeller, in revolving, causes the water with which the casing is filled also to revolve, when centrifugal force comes into play, and the water tends to fly away from the centre toward the outside of the casing. An outlet D is arranged in the casing, through which the water can escape. Naturally the water flying away from the centre tends to create a vacuum at the centre of the impeller, which is utilised for drawing more water through the pipe E into the casing, to take the place of that which has been forced out through the outlet D; and so a constant stream is kept up, no valves at all being required.

It will be noticed in the sketch that the impeller is not in the centre of the casing (which also is not quite circular), but nearly touches it just below the outlet D, so that the water, when it leaves the outside of the impeller, instead of churning round in the casing, is caused by its direction of motion (as shown by the arrow), as well as by the pressure set up at the outer part of the casing by the centrifugal force acting on the water spinning round with the impeller, to flow out through the outlet. As the water naturally leaves the impeller all round at once, this eccentricity of the casing serves another useful purpose, giving a passage for the water, increasing gradually in volume from nothing just below the outlet to full opening by the time it reaches the outlet, the direction of rotation being as shown by the arrow.

In actual practice, the inlet pipe E is generally made in one with the casting of the casing and is forked, to pass on either side of the outlet, as shown in Figs. 126 and 127, so that the water shall reach the impeller from both sides.

The "vanes" of the impeller, instead of being made straight, as shown in Fig. 125, are curved back toward their ends, so that in addition to imparting rotary motion to the water entering the impeller through the pipes E E to obtain the centrifugal force, they act on this water like wedges, forcing the water outward and away through the pipe D.

Generally the vanes forming the actual impeller are arranged between two side plates, shaped as shown in Fig. 127, which serve to support the vanes and make the impeller stronger, but this is not always the case, as the side plates are not essential to the action of the pump.

The shaft B, which is of gun metal (as are all other parts of the pump), is either made in one piece with the impeller, or else is separate and the impeller "keyed" on to it.

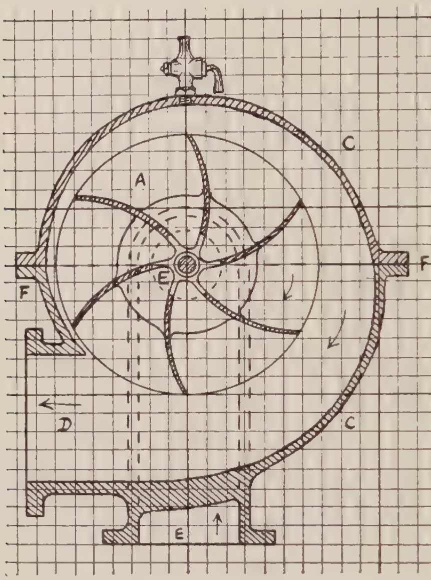


FIG. 125

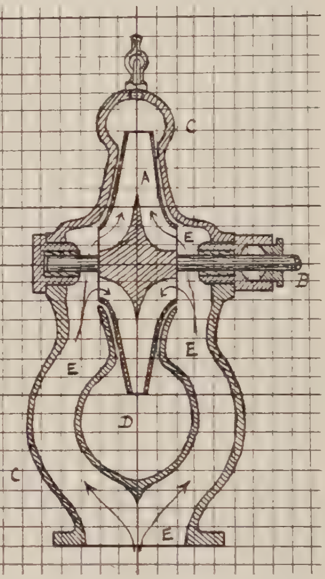


FIG. 127

It runs in bearings at either side of the casing, the bearing surfaces being made of a very hard wood called lignum-vitæ, the water acting as lubricant, which arrangement gives excellent results. These bearings are generally made in the form of "bushes," or hollow cylinders, of the lignum-vitæ, fitted into the casing. The casing itself is made in two parts, as shown at F F in

Fig. 126, the inlet and outlet pipes both being attached to the lower part, so that the upper part may be removed for examination of the impeller without disturbing the pipe joints.

Naturally, screw-down valves are fitted both on the inlet pipe leading from the sea to the pump and on the discharge pipe leading from the condenser overboard, to allow of the pump or condenser being opened out for examination, without letting water into the ship.

The circulating pumps are driven by separate engines, and generally each set of main engines has its own condenser and circulating pump.

CHAPTER VII

THE COMPOUND ENGINE

WHEN considering the simple engine, using the steam "expansively," we said on page 96 that there were practical objections to using a "high ratio of expansion" in the simple engine, that is, cutting off the steam very early in the stroke, and allowing its expansive force to drive the piston to the end of the stroke, thus getting as much work as possible out of the steam before allowing it to escape to the condenser.

Let us see what these practical objections are.

We must first learn a little more about the steam from which we get our power.

Steam, we know, is obtained by raising water to that temperature at which it can no longer exist *as water*, but changes its state and becomes steam, and keeping the water at that temperature until it has all boiled away.

COMBUSTION

The heat required is obtained by the "combustion" of fuel, the chief chemical constituents of which (whether the fuel be coal, oil, or wood) are the solid carbon and a gas called hydrogen combined together. Combustion or burning is simply the *rapid chemical union of the carbon and hydrogen of the fuel with the oxygen of* *the air*, the carbon "combining" with the oxygen (as we see when considering the subject of "smelting" iron ore) to form a gas called "carbonic acid gas," and the hydrogen combining with the oxygen to form *water*, which is an "oxide" of hydrogen, which also passes off in the form of a gas. This "chemical combination" is attended by great heat, and the resulting gases are given off at a very high temperature.

If, then, the burning of the fuel takes place in the furnace of a boiler, the heat generated by the burning will be transmitted or "conducted" through the metal of which the furnace is made to the water on the other side of the metal.

HEAT

Now what is this heat which we are able to transfer from the burning fuel and the hot gases, through the metal walls of the furnace, to the water?

When considering the subject of lubrication (see p. 28) we saw that when friction occurred between two surfaces rubbing together heat was generated. So, in the case of the thrust block, we lubricated the thrust collars and rings to reduce the friction as far as possible, and to carry off such heat as was generated by the friction we could not do away with.

In the absence of this lubrication the shaft would revolve very stiffly, much of the power used to turn the shaft being swallowed up in overcoming the friction of the thrust collars, and the result of this friction would be that less power would be available for turning the propeller, and the collars would soon become hot and would wear away. The power which was "lost" in overcoming the friction of the thrust collars against the rings was converted into heat.

If we vigorously rub a piece of wood with sand-paper we soon find that the sand-paper becomes very hot, and our fingers suffer, part of the "mechanical energy" we are expending in overcoming the friction between the sand-paper and the wood doing actual "mechanical work" in wearing away the wood, and part of it being converted into heat. From this we may conclude that mechanical energy can be converted into heat, and that heat is really a form of mechanical energy.

APPLICATION OF HEAT TO WATER

Let us now consider what actually happens when we apply heat to water.

When we first considered the generation of steam we merely said that the application of heat to water caused the water to boil away and become steam, which we used in our engine.

From the definition of heat at which we have just arrived we see that mechanical energy has been expended in turning the water into steam, and this mechanical energy, stored up in the steam, really is the source of the power of the steam engine.

When we say that a block of lead weighs so many "pounds," or that a vessel contains so many "cubic feet" of water, we know what "quantity" of lead there is in the block, and what "quantity" of water the vessel contains, as a pound and a cubic foot are known measures of weight and volume.

So with heat, we must have some known measure of quantity, in order that we may be able to tell *how much* heat is required to produce any given result; such, for instance, as the raising of a given quantity of water from a certain temperature to any other higher temperature.

THE BRITISH THERMAL UNIT

In England our measure of weight is the "pound" avoirdupois, and our measure of temperature is the "degree," as shown by the Fahrenheit thermometer.

So the English measure of quantity of heat uses the pound avoirdupois and the degree Fahrenheit as bases, and the *quantity of heat required to raise the temperature of* 1 *lb. of cold water through* 1 *degree Fahrenheit* is taken as this measure, to which all quantities of heat are compared, and this measure is called the "British thermal unit" (generally written B.T.U. for shortness).

As an example, let us take, say, 10 lbs. of water at 40 degrees Fahrenheit, and apply heat to it until its temperature has risen to 50 degrees. Then the quantity of heat which will have been put into the 10 lbs. of water will be

$$10 \times (50^\circ - 40^\circ) = 10 \times 10 = 100 \text{ British thermal units.}$$

We know the temperature of melting ice to be 32 degrees Fahrenheit, and we know that as the ice melts the water remains at this temperature until all the ice is melted. This will be a convenient temperature from which to commence when studying the application of heat to water.

Also we know the temperature of boiling water, at atmospheric pressure at the sea level, to be 212 degrees Fahrenheit.

Let us then start with 1 lb. of ice-cold water and apply heat to it.

As we apply the heat the temperature commences to rise, and continues to do so until boiling point is reached, no change having, up till now, taken place in the water other than its increase in temperature.

We see that the quantity of heat we must have applied to cause this change of temperature is

$$1 \times (212^\circ - 32^\circ) = 1 \times 180 = 180 \text{ B.T.U.}$$

This heat, the result of the application of which to the water can be felt and is shown by the rising of the thermometer, is called "sensible heat."

On applying more heat to this water already at boiling point, it comences to boil, turning into steam, but the temperature of the boiling water does not change, in spite of the extra heat, and the steam is given off at this same temperature of 212 degrees.

This "change of state" from water to steam continues, without any change of temperature, until all the water has been turned into steam, and the quantity of heat required to effect this change of state of the 1 lb. water at 212 degrees to 1 lb. steam, also at 212 degrees, has been found to be 966 British thermal units.

This quantity of heat, expended in changing the state from water to steam without changing the temperature, is called the "latent heat of steam," and as heat, we have seen, is merely a form of mechanical energy, we may conclude that as mechanical energy has been put into the water to turn it into steam, this same amount of mechanical energy will be given back on the steam turning again into water.

When we talk of the "boiling point" of water as being 212 degrees, we are supposing the pressure at which this boiling takes place to be atmospheric pressure, as the boiling point rises when the pressure becomes greater, checking the steam bubbles from forming.

For instance, the boiling point of water under a pressure of 53 lbs., as shown by the pressure gauge, is 300 degrees, and at 235 lbs. pressure it is 400 degrees.

Naturally we would conclude from this that the quantity of heat required to convert the 1 lb. of water at boiling point into steam at high pressure must necessarily be greater than that required to convert it into steam at atmospheric pressure, as the resulting steam is at a higher temperature. This is actually the case, but not to the extent one would imagine, as it has been found that the latent heat of steam *diminishes* as the pressure under which it is generated increases. But as the temperature of the water has to be raised before it will boil under the increased pressure, a certain number of thermal units are required to raise the 1 lb. water at 212 degrees up to this new boiling point before any of the water can be turned into steam. This amount is, of course, sensible heat, as the temperature of the water rises, and this increase in sensible heat more than counterbalances the decrease in latent heat, and the "total heat of evaporation" is greater.

Taking steam at the two pressures considered above, namely 53 lbs. and 235 lbs., the different values stand thus:—

Pressure in lbs. above atm.	Temperature of boiling point.	Latent heat in B. T. U.	Sensible heat from 212.	Total heat of evapn. from 212.
0	212	966	0	966
53	300	902	90	992
235	400	829	194	1023

Treating heat as mechanical energy, we see that a very large and increasing quantity of mechanical energy is required to convert water into steam at high pressures, and so more and more mechanical energy is stored up in that steam as the pressure becomes higher, to be given back in actual work performed on the piston in the engine, and transmitted through the mechanism to drive the ship, when the steam, cut off early in the cylinder, falls in pressure as it drives the piston before it through its stroke, and is finally turned back into water in the condenser.

To apply this knowledge of some of the properties of steam to our simple engine.

Let us take one particular case as an example, say our 135 lbs. pressure, as shown by the pressure gauge, cut off at one-tenth stroke in the cylinder, on page 46.

The temperature of the steam on entering the cylinder at 135 lbs. pressure is 358 degrees, while its temperature at the end of the stroke, when it had fallen to 15 lbs. or atmospheric pressure, would be only 212 degrees. Supposing the engine to be "non-condensing," then throughout the return stroke the pressure on this side of the piston would remain at that of the atmosphere, and so the inside of the cylinder would cool down very considerably below the temperature of the boiler steam.

Naturally on starting the next stroke, the new steam at 358 degrees would be robbed of a considerable portion of its heat in again raising the temperature of the walls of the cylinder, with the result that some of it would be condensed on the comparatively cool sides of the cylinder, and on the next return stroke this condensed steam would pass direct to the exhaust and be lost, having done no work in forcing the piston forward.

If the engine be "condensing," this loss by liquefaction would be very much greater, as the temperature of boiling point in the condenser is as low as 100 degrees, owing to the vacuum. As the cylinder is open to the condenser for nearly the whole of the return stroke, the cooling of the walls of the cylinder would be very considerable, and the waste of heat proportionately greater.

Generally, the greater the difference between the temperature and so the pressure of the steam on entering the cylinder and on leaving it, the greater the waste of heat or mechanical energy due to liquefaction.

To reduce this waste, it is evident that the temperature and so the pressure of the steam during exhaust must be kept more nearly equal to its original temperature and pressure.

But in order to obtain efficiency we know that it is necessary to utilise the expansive force of the steam, so as to get the largest possible amount of work out of it.

To get over the difficulty, the compound engine is used. In the compound engine, instead of doing the whole of the expansion of the steam in the one cylinder, the temperature of which will vary so largely during the stroke, the expansion is carried out in two, three, or even four separate cylinders, the variation in temperature in any one of which will naturally be very much smaller.

ARRANGEMENT OF THE COMPOUND ENGINE

The arrangement adopted is that the steam at boiler pressure is first used in the high-pressure cylinder, as in a simple engine, being cut off comparatively late in the stroke, and the exhaust steam from this cylinder, instead of being led direct to the condenser, passes into a "receiver," from which it is led to the slide case of the next cylinder, called the "low-pressure" cylinder (where two cylinders are used, or the "intermediate," where there are three), and from this slide case the slide valve admits it to the low-pressure cylinder in the usual manner, the receiver practically forming the boiler for supplying the steam to this cylinder, the steam in this "boiler" being the exhaust from the high-pressure cylinder. The arrangement of an ordinary compound engine is shown in Fig. 128.

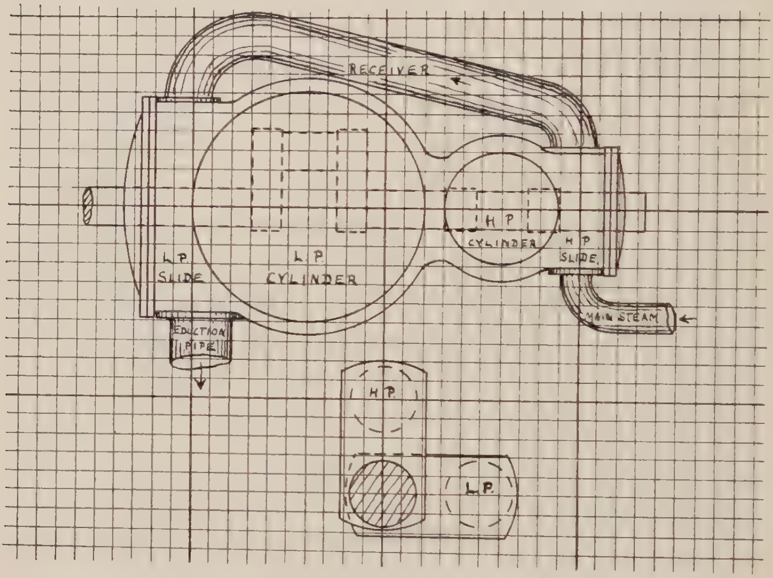


FIG. 128

Obviously, the back pressure in the high-pressure cylinder is practically the receiver pressure, so the effective pressure on the high-pressure piston at the early part of the stroke is not so excessive as in the case of the simple engine.

In the first compound engines, this receiver was made of considerable size, so as to keep the pressure of the steam on entering the low-pressure cylinder steady; but this was soon found to be unnecessary, and the receivers now are merely steam pipes of sufficient size to allow of the free flow of the steam from the exhaust of the high-pressure cylinder to the slide case of the low pressure.

RELATIVE SIZES OF CYLINDERS

The low-pressure cylinder is usually made double the diameter of the high, and so four times its volume; so supposing the steam to be cut off at half-stroke in the high pressure, it would be expanded eight times before finally passing to the condenser, thus giving a fairly high "ratio of expansion," yet the variation in pressure and temperature in either cylinder would be comparatively small, and the high-pressure cylinder, whose temperature would naturally be high, would never be exposed to the low temperature of the condenser.

Consequently the amount of liquefaction in either cylinder is much reduced, and the steam, which, on entering the high-pressure cylinder, is liquefied by that cylinder being at a lower temperature than the steam, is re-evaporated by the heat of the cylinder when the pressure falls, and so passes into the low-pressure cylinder as steam, and there does its work, not being lost as would have been the case had it passed direct to the condenser.

OTHER GOOD POINTS OF THE COMPOUND ENGINE

In addition to this increase in the efficiency of the steam gained by the use of the compound engine, another very important point is scored.

In the simple engine, if the steam be cut off very early in the stroke, in order to get as much power as possible out of it, the full boiler pressure acting on the piston during that part of the stroke brings very heavy strains to bear on all parts of the machinery; when the piston is nearing the end of the stroke and the pressure has fallen very low these strains are proportionately reduced.

As of course the piston-rod and all other parts of the engine have to be made strong enough to stand the greatest strains ever brought to bear on them, their strength and weight, necessary on account of this great strain at the beginning of the stroke, are very much greater than are needed to stand the reduced strains when nearing the end of the stroke, the pressure having fallen so much.

With the comparatively low rates of expansion in any one cylinder in a compound engine, the strains do not vary nearly so much during the stroke, and so the sizes necessary for the strains at the beginning of the stroke are much more nearly those required for the strains at the end of the stroke, and much unnecessary weight is saved.

Also, the large variation in the strain during the stroke in the simple engine tends to cause jerkiness of action, most of the work being done at the beginning of the stroke; in the compound engine, this jerky action is much reduced.

The arrangement of two cylinders, dividing the expansion of the steam into two stages, though very suitable for the moderate steam pressures used a few years ago (about 60 lbs., as a rule), still allows of a larger range of temperature than is desirable where the present pressures of 200 lbs. or more are used. Consequently most modern marine engines are made to divide the expansion into three stages instead of two, generally using three cylinders, known as the "high," the "intermediate," and the "low" pressure.

In such an engine there would be two receivers, the intermediate between the high and intermediate pressure cylinders, and the low pressure between the intermediate and the low-pressure cylinders.

Engines of this type are known as "triple expansion" or "triple compound," and though three cylinders is the general rule in large engines, the low-pressure cylinder is often, on account of its large size, divided up into two smaller ones of the same total volume as the one large one. In this case there are, of course, four cranks, one for each cylinder.

POSITIONS OF CRANKS IN COMPOUND ENGINES

In the two-cylinder simple engine we saw that the best position for the two cranks was at right angles to each other, as by this arrangement the "turning moment" on the crank shaft was kept almost constant.

In the ordinary compound engine also this arrangement is found to be the best, the high-pressure crank generally being in advance of the low-pressure when going ahead.

In the three-cylinder triple expansion engine the three cranks are usually set at equal angles apart, while in the four-cylinder triple expansion and in the quadruple expansion engines each crank is at right angles to the next.

The arrangements of the ordinary compound engine with its two cylinders, the three-cylinder triple expansion, and the four-cylinder triple expansion engines are shown in Figs. 128, 129, and 130.

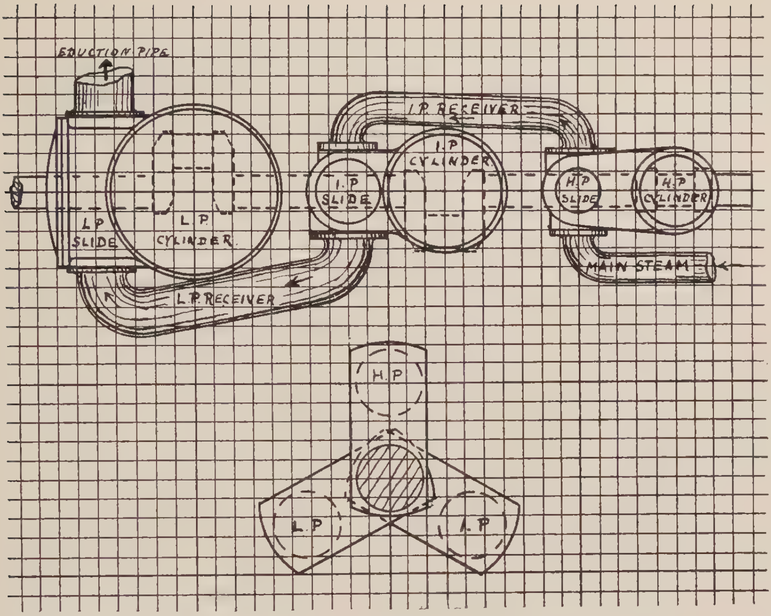


FIG. 129

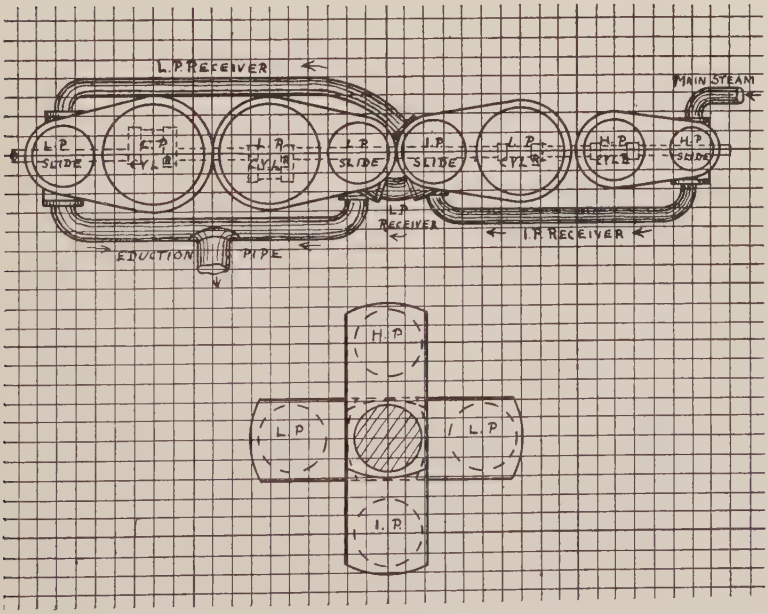


FIG. 130

CHAPTER VIII

THE BOILER

THERE are so many types of boiler that it is not advisable here to enter into any detailed descriptions, but the general principles which govern all types may be briefly sketched.

The object of all boilers is to maintain a constant supply of steam for the engines at the desired pressure, and to give that supply on the smallest possible expenditure of fuel.

On board ship, where space and weight are matters of such great importance, naturally it is desirable to use the smallest and lightest possible boiler capable of keeping up the supply of steam, so that there may be more space available for the stowage of the fuel to enable the ship to steam long distances without renewing her supply.

In all ships except the smallest ones, instead of having only one boiler (which would necessarily be very large to supply so much steam), a number of boilers of more moderate dimensions are used, and all these boilers are arranged so that they can be connected to the one main steam pipe leading to the engines.

In order to use the fuel economically, it is necessary to arrange that the heat shall be able to pass as freely as possible from the fire and the hot gases resulting from the combustion of the fuel to the water which is to be turned into steam, and as only a certain fixed amount of heat can pass through metal of a given thickness in a given time, it is necessary that there shall be sufficient "heating surface" to allow as much as possible of the heat from the fuel to reach the water, else there will be a great waste of heat by the gases going away up the funnel at a very high temperature, not having been able to part with sufficient of their heat to the water.

In order to obtain this heating surface, the most usual plans are, either to pass the flame and hot gases from the furnace, which is surrounded by the water which is to be turned to steam, through a large number of tubes round which also is the water—furnace and tubes being enclosed in a "shell," generally of cylindrical section with flat ends—or else to let the heat act on the outsides of tubes containing the water, the steam from these tubes passing into a "collector" common to all of them.

The former of these types, where the heat passes *through* the tubes, the water being round them, is known generally as the "Scotch" or "tank" boiler, while the latter, where the heat is outside the tubes and the water inside, is known as the "water-tube" type.

As only a given amount of heat is given off by the combustion of a certain quantity of fuel, this amount varying largely with different sorts of fuel, it is necessary that a large quantity of the fuel be burned in a small space, else the furnace would be too large. This can only be done by supplying air rapidly enough to cause the complete combustion of the fuel in a short time.

We know the effect of using the bellows to blow up a fire, the rapid supply of air to the fire causing it to burn fiercely; the same effect is obtained by the stretching of the newspaper across the front of the open fire-place above the grate, when all the air drawn up by the draught of the chimney has to pass through the fire.

So in the furnace of our boiler the draught must be kept up, whether by making the "chimney" do its work to the best advantage, or else by the use of bellows or "fans," generally worked by engines driven by steam from the boiler.

MOUNTINGS NECESSARY FOR BOILERS OF ALL TYPES

The feed check valve. — We saw when considering the means of supplying steam to the engines on p. 47 that a pump called a "feed pump" was used to feed the boiler with water to take the place of that which passed away to the engines in the form of steam. As it is necessary to be able to control the amount of water pumped into the boiler by the feed pump so as to keep it at its proper level, a screw-down non-return valve known as a "feed check valve" is arranged on the boiler to check or regulate the flow of feed water from the feed pipe into the boiler. Being a "non-return" valve, it is impossible for hot water to flow back from the boiler into the feed pipe in case the pump should

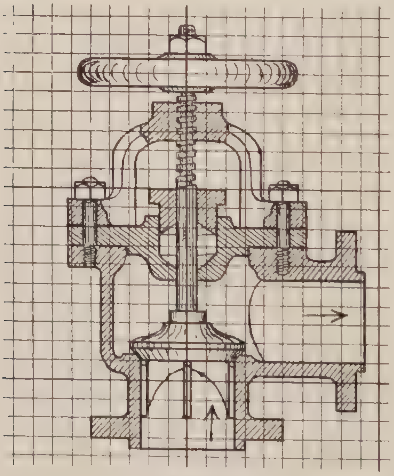


FIG. 131

be stopped. By screwing down the spindle by means of the hand-wheel, the valve can be held firmly down on its seating, so that no water at all can enter the boiler, or by easing back the hand-wheel the necessary distance, the quantity of feed can be exactly controlled.

Fig. 131 shows a section of a feed check valve.

Safety valve.—Should the pressure rise too high, the boiler, being designed to stand only a certain pressure, must burst unless the excess of pressure be relieved. Suppose the engines are suddenly stopped when the fires are burning fiercely, the generation of steam still goes on, but as the engines are no longer taking any away, the pressure must naturally rise to a dangerous extent unless means be provided to allow of its escape.

This means of escape is supplied by the safety valve.

The general idea of the safety valve is very simple, consisting essentially of a hole, controlled by a stopper, through the top of the boiler, leading from the steam space, through which hole the steam can escape direct to the open air.

This hole forms a "valve seating," and is closed by an ordinary valve, generally of the "conical" type. The valve is held down on its seating by pressure applied to its top either by a weight or by means of springs, so that when the pressure in the boiler rises high enough, it will force the valve up off its seating against this counter-pressure and the steam will escape through the hole, the pressure in the boiler thus being prevented from rising any higher.

Naturally such a crude arrangement as this would not do in real practice, so a valve box is bolted on to the top of the boiler over this hole, the interior of the valve box being in direct communication with the steam space of the boiler. In this valve box are two or more seatings, closed by valves held down on the seatings by springs fixed to the cover of the valve box. From the upper part of the valve box, above the valves, a pipe is led away to the open air.

The pressure which must be exerted by the springs to keep the valves on their seatings against the pressure inside the boiler can very easily be calculated. Suppose the boiler pressure to be 200 lbs. per square inch and the diameter of each valve seating to be 3 in. Then the area of the under-side of the valve, which will be exposed to the boiler pressure, will be 7 square inches.

So the total upward pressure on the valve will be :—

$$7 \times 200 \text{ lbs.} = 1{,}400 \text{ lbs.},$$

and the spring must be adjusted to exert this pressure on the back of the valve.

Naturally if the pressure inside the boiler rise above 200 lbs., it will force the valve up off its seating against the downward force of the spring and the steam will escape, preventing any further rise of pressure.

As soon as the pressure inside the boiler has fallen again to the 200 lbs. the spring will reassert itself and close the valve, keeping the pressure at the 200 lbs.

We have said that weights or springs can be used to keep the valves down on their seatings, but though this is generally the case, weights would not do on board ship, on account of the effect the pitching and rolling of the ship would have on the weights themselves; so for all ship work we must confine ourselves to the use of springs only.

Two or even three separate valves are fitted in the one safety valve box, so that, should one of the valves by any means become jammed, we would still have the other or others to rely on, each valve being designed to allow of sufficient steam to escape, independent of the others, to prevent an accident through excessive pressure.

In all safety valves, arrangements are made to enable the valves to be lifted by hand off their seatings, against the pressure of the springs, so as to ensure their being free and in proper working condition at all times.

Fig. 132 shows the front elevation, half in section, of

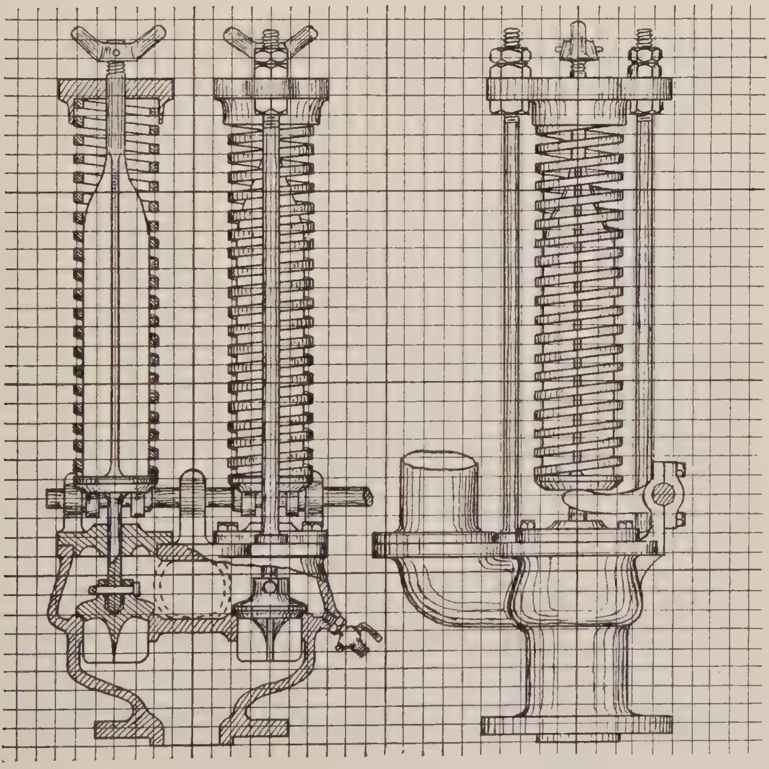


FIG. 132

FIG. 133

a safety valve, of which Fig. 133 is the end elevation, showing the lifting gear.

The stop valve.—As the feed check valve regulates the supply of feed water to the boiler, so the stop valve regulates the flow of steam from the boiler. In the chapter on cocks and valves on page 129 we have already considered the subject of the stop valve, and Fig. 117 shows the construction of a "self-acting stop valve," so it will suffice to refer back to that chapter with regard to the stop valve as a boiler mounting.

Water gauges.—That the water in the boiler should be kept at the correct level is a matter of great importance. If the water level be too high there is great danger of water passing over with the steam to the engines. We saw the necessity for "cushioning" in the cylinders in order to ease the shock of the reversal in direction of motion of the reciprocating parts of the engine, and also we saw the necessity for "clearance" at the end of the stroke, so that the piston should not by any possibility strike the ends of the cylinders.

Water we know to be incompressible, so if a quantity of water find its way into the cylinder with the steam, this water coming, at the end of the stroke, between the piston and the end of the cylinder, would be almost equivalent to doing away with the clearance, and there would be a heavy shock each time the piston reached the end of the stroke. In fast-running engines this might be very serious, resulting in the breaking of the cylinder or piston.

This passing of water from the boiler to the engines is called "priming," and must be avoided.

On the other hand, should the water level in the boiler be too low, some part of the heating surface will not be covered with water, with the result that the metal will be overheated at that point and will very probably give way.

This "shortness of water" is the most fruitful cause of boiler explosions.

In order to be able to tell accurately at what level the water stands in the boiler, "gauge glasses" are used.

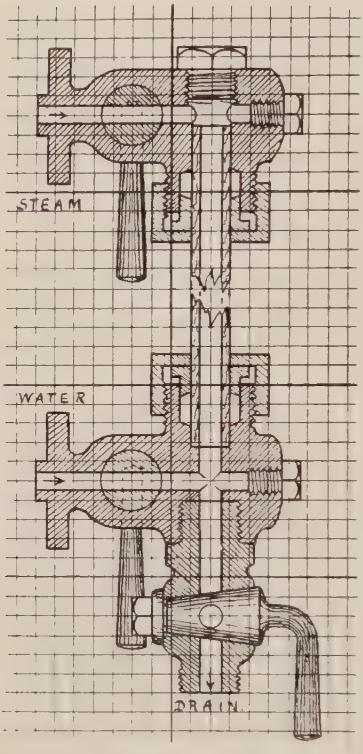
The gauge glass consists of a strong glass tube connected at the top end with the steam space of the boiler, and at the lower end with the water space, and arranged on the front or side of the boiler at such a height that the middle of the gauge glass will be at the height of the correct working level of the water in the boiler. The lower end of the glass should be an inch or so above the highest part of the heating surface, so that so long as water is visible in the glass the boiler will be safe.

Obviously the level of the water inside the boiler will always be shown by the height of the water in the gauge glass.

As gauge glasses are liable to break it is necessary to be able to shut off both the steam and the water from the glass, and to this end cocks are fitted on the two pipes leading from the inside of the boiler to the gauge glass.

Means must also be provided to enable a broken glass quickly to be removed and replaced by a new one.

Also, the gauge glass and the passages to it from the boiler are liable to become choked by sediment floating on the surface of the water, which necessitates a drain cock being fitted at the bottom end of the glass, by means of which the gauge glass and the passages may be "blown through" to clear them.



FIGS. 134, 135

The general arrangement of a gauge glass and its fittings is shown in Figs. 134 and 135.

Pressure gauges. — The working of the engines depending entirely on the steam pressure in the boiler, it is naturally necessary that we have some reliable means of telling at all times what that pressure is.

In our experiments to demonstrate Boyle's Law (on pages 43 and 45) we measured our pressure in two ways—

(1) By the height of the column of mercury which the pressure would support.

(2) By the actual weight which the pressure would support when acting under a piston of known area, on which the weight was fixed.

Obviously neither of these plans is suitable for work on board ship, so what is known as the "Bourdon pressure gauge" is used, the principle of which is very simple.

A curved metal tube of oval section, closed at one end, is connected by a small pipe to the boiler, so that the interior of the tube is subject to the steam pressure.

The tendency of the pressure inside the oval tube is to cause it to become more nearly round in section (*e.g.* the inflating of the inner tube of a bicycle tyre, which, when empty, is flat, but when inflated becomes round).

As the oval tube is arranged edge-on to the way in which it is curved, the tendency is for it to straighten itself when the pressure inside it is increased, and its section becomes rounder, and the greater the pressure the greater this tendency. So the closed end of the tube will naturally move as the tube alters its curvature,

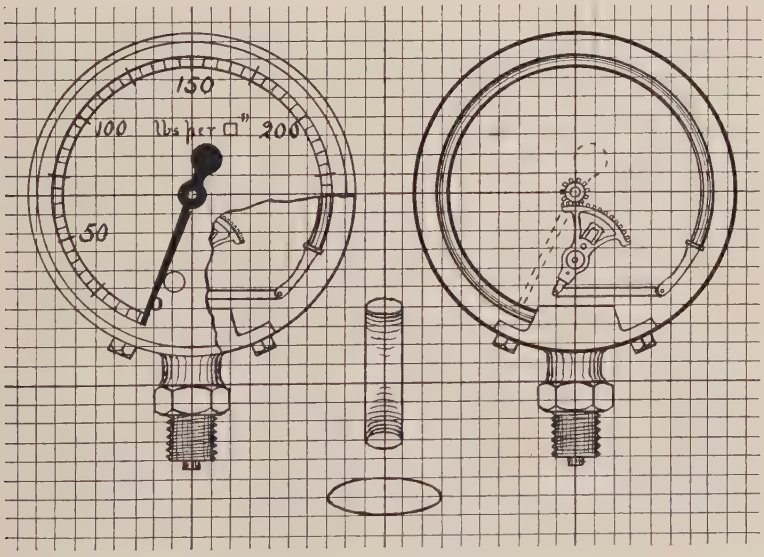


FIG. 136 FIG. 138 FIG. 137

the other end being fixed, and by the amount of this movement we can tell the pressure. To make the indications more readable, this motion is multiplied and transmitted by a simple mechanism of toothed wheels to a pointer, revolving about the centre of the gauge and showing on a scale marked round the face of the gauge the pressure inside the tube.

The marking-off of this scale is done by comparing with a mercury pressure gauge of the type already considered on p. 43.

The arrangement of the Bourdon pressure gauge is shown in Fig. 136, Figs. 137 and 138 showing the curved tube and an enlargement of its section.

CHAPTER IX

MATERIALS USED IN THE CONSTRUCTION OF THE STEAM ENGINE AND OF MACHINERY GENERALLY

ROUGHLY speaking, the raw material is brought into the required shape and ready for "machining" and "fitting" into its place in the engine by one or other of two methods.

These are—

(1) "Casting"—where the material is melted in a furnace, and while in the molten state is poured into a "mould" of the exact shape required. When the molten metal has solidified, the mould is removed, the casting being completed.

(2) "Forging"—where a mass or "ingot" of the metal is gradually worked into the required shape by hammering, sometimes cold, but very much more generally at or about a red heat.

In both cases any working surfaces or parts which are required to fit accurately are left somewhat large, to allow for machining and fitting them into perfect accuracy, as this cannot be obtained either by casting or by forging.

CASTING

The process of casting is roughly as follows:—

First, a wooden "pattern" is made of the exact shape and a very little larger than the object required.

Then a special sort of sand called "moulding sand" is carefully packed round the pattern, a "box" (which is really like a box without top or bottom) being placed round the pattern to keep the sand in place. This sand is made a little damp in order to make it "bind." On a very frosty day snow will not bind and we cannot make snowballs of it, it is so dry and crumbly. When, however, it is less cold and the snow is inclined to thaw and so become damp, it binds well, but it must not be too wet. The sand binds in much the same way when damp.

The mould is so made (generally in two parts) that the wooden pattern can be removed, leaving a hollow space in the sand of the exact shape and size of the pattern, and a hole is made from the top of the sand leading into the inside of the mould, this hole being called the "runner," and through it the molten metal is "run" into the mould.

After the pattern has been withdrawn the mould is dried on the surface to make it harder, so as to stand the rush of the metal when it is poured in.

When the metal has "set" or become solid and cooled down, the sand of the mould is broken away, leaving the casting of the same shape and nearly of the same size as the pattern.

Nearly all metals shrink more or less on cooling, so it is necessary to make the pattern a certain amount larger than the casting is to be when finished.

The arrangement of a mould for casting a simple object such as a short solid cylinder is shown in Fig. 139. The mould in this case is made in two halves in two boxes, half the pattern being in either box.

A is the "runner," B the actual mould, and C the "riser" or "vent" to allow the air to escape from the inside of the mould as the metal is poured in. This also permits any dust which may be in the mould to float upon the top of the molten metal through the riser, and prevents it spoiling the casting.

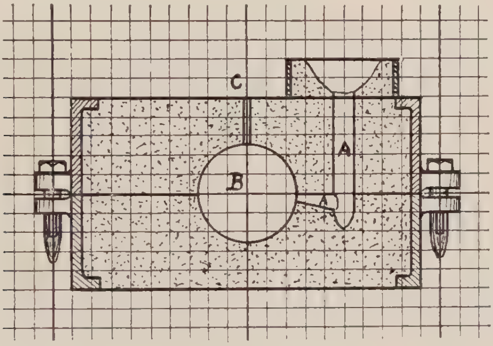


FIG. 139

When the metal comes up in the riser, we know that the mould is full.

The two halves of the box are fixed together by means of "cotters" or wedges passing through pins fixed to the one part of the box, and passing through suitable projections in the other part, to prevent the pressure of the molten metal in the mould from forcing the two parts asunder, and allowing the metal to escape. In small castings, instead of "cottering" the boxes together, it is usual to place weights on the top of the mould, which answers the same purpose, and saves time.

Where hollow spaces are required inside a casting, "cores" of moulding sand or "loam" are made, of the exact shape of the required hollows, and are put in position inside the mould, supported by projections on the ends of the core which fit into hollows arranged to receive them in the mould itself; these hollows are made when preparing the mould, by pieces of wood called "prints" fixed on to the pattern in the necessary positions.

Fig. 140 shows the section of a T-shaped piece of pipe, for which Fig. 141 is the pattern, BBB being the prints, and Fig. 142 shows the lower half of the mould, in plan, A, the core, being supported at BBB, C being the runner, through which the metal is poured into the mould.

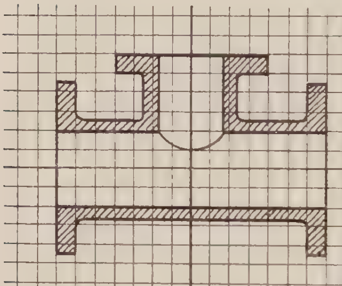


FIG. 140

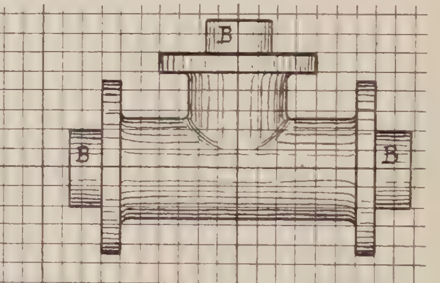


FIG. 141

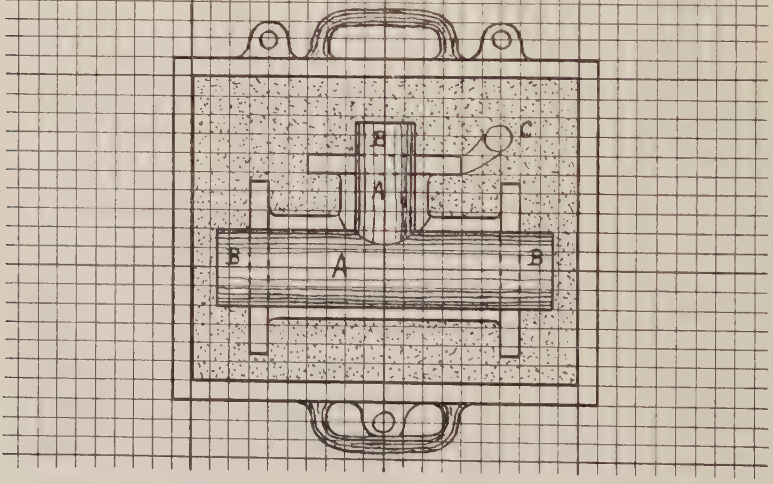


FIG. 142

A riser would be arranged in the top half of the mould, leading from the top of one of the flanges.

These cores are made in a "core box," which is practically a wooden mould, into which the sand is "rammed," and after removal from the core box, the core is carefully dried to make it strong enough to handle and to stand the rush of the metal when it is poured into the mould.

When the casting is taken out of the sand the core is broken up and removed, leaving the hollow space clear.

Naturally, in this process, a new mould has to be made for each casting, the mould being destroyed, as we have seen, in removing the casting. The sand can, however, be used over again many times, though it gradually loses its "binding" power.

FORGING

Forging, the other method by means of which the raw material can be brought into shape, merely consists of hammering it when made soft by being heated to a red heat, in such a way that it gradually assumes the required shape.

Some sorts of forgings can be made by squeezing the red-hot metal into iron moulds called "dies" by means of hydraulic presses. Such forgings, however, can only be of comparatively simple form, and the dies are very expensive to make, so unless a large number of forgings of exactly the same pattern are required, it would not pay to use this process. In forging, it is not always convenient to make the object out of one single piece of metal, so it is built up, piece by piece, more metal being added on by "welding" where required. Welding consists of bringing the two pieces together at a "welding heat" (which is about what is popularly known as "white heat") and hammering them thoroughly at the junction, when the two parts unite and practically become one piece, a good weld being as strong as the original metal, or even stronger.

Forging generally is a much more expensive process than is casting, unless the object be a very simple one.

IRON

The material most extensively used in engineering work is iron, which is obtained from iron ore by a process called "smelting."

This process differs for the various sorts of iron ore, several of which are found in Great Britain.

Generally, iron ore consists of a combination of pure metallic iron with a gas named oxygen, which is one of the constituents of air, and is the part of the air which supports life, and which is used up when anything is burned.

When a piece of iron has long been exposed to the action of the air and moisture it becomes "rusty," that is, it has slowly combined with the oxygen of the air and turned back into one form of iron ore. This gradual "conversion" of iron back into an iron ore takes place much more rapidly in the familiar laboratory experiment of burning a bundle of thin iron wire in a vessel containing oxygen gas, a little powdered sulphur having been put on the end of the wire and lighted before plunging the bundle into the oxygen, to start the process. This burning is simply a rapid combination of the metallic iron with the oxygen, forming an "oxide" of iron, just the same as burning a piece of charcoal or carbon, as it is called in chemistry, in air, when the carbon rapidly combines with the oxygen of the air to form an oxide of carbon, except that in this case the product of the combustion is a gas, instead of a solid, as is the case when the iron is converted into an oxide.

In smelting, this process has to be reversed, the oxygen having to be removed from the iron ore, so as to leave the iron only behind.

To remove the oxygen, carbon is used. The fuel (coal and coke consist chiefly of carbon), which also supplies the heat required to make the chemical action take place, providing this carbon. A mixture of coke and iron ore is placed in a furnace, and the coke is set on fire, a "blast" of air being forced into it to make it burn fiercely and give the necessary heat.

As the fuel burns it not only combines with the oxygen of the air, but also combines with the oxygen of the iron ore, leaving the iron free, the oxide of the carbon passing off as a gas. During this process of removing the oxygen from the ore a considerable quantity of carbon combines with the iron, and this carbon renders it much more fluid—the pure iron at a high temperature simply being a pasty mass, unable to run into any sort of mould.

This combination of iron and carbon is run out of the smelting furnace into rough shallow sand moulds, and is called "pig iron."

From this pig iron, cast iron, steel, and wrought iron are made, these three being simply iron with more or less carbon in combination, in the case of cast iron and steel. If this pig iron be again melted by means of heat in a furnace, it becomes quite fluid and can be run into the moulds made of the required shape in the manner we have seen, and the result is—iron castings.

As we have said, cast iron contracts on cooling, and due allowance must be made for this contraction in the patterns, which have to be somewhat larger in all directions than the castings are required to be when finished.

Castings generally are of irregular shape and thickness to suit the various purposes for which they are intended, and naturally the thin parts cool very much more rapidly than do the thick.

The consequence is that the thin parts "set" and become solid while the thick parts are still more or less liquid, with the result that the thick parts tend to break away from the thin, when they in turn become solid.

Naturally, very heavy strains result in the castings themselves, rendering them unreliable and subject to fracture without apparent reason. So great, indeed, are these unknown "internal stresses" that sometimes castings are found to be already fractured by the strains set up in themselves, on taking them out of the mould.

To reduce as far as possible the evil effects of this unequal shrinking of the various parts of the casting as they cool, all parts should be made as nearly as possible of one thickness, and where this is impossible, as is very often the case, the change from a thin part to a thick should be made gradual, by rounding off the corners at the junction, as shown in Fig. 143, where the corners at the root of the thin "web" are rounded off where they meet the thick part. Were this not done, fracture would almost certainly take place at the root of the web, as shown in Fig. 144.

Generally, changes in shape or thickness in castings should be made as little abrupt as possible on this account.

Cast iron is also liable to "blow-holes" or bubbles forming underneath the surface during "solidification," like the air bubbles one sees in ice (which, however, are due to a very different cause); but as these cannot be seen in the iron, we cannot tell how much the casting may be weakened by them, as naturally, there being that amount of metal less to stand the strain, the casting must be weakened where the blow-hole is.

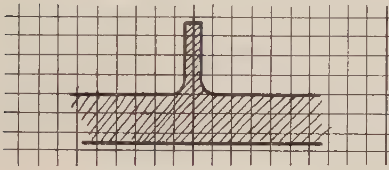


FIG. 143

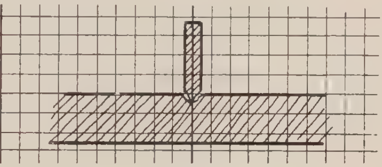


FIG. 144

In consequence of these bad properties of cast iron, it is necessary to allow a very large "margin of safety" in iron castings, that is, the thickness must be considerably greater than would be necessary if the material were entirely reliable, to allow for possible defects.

Cast iron is much stronger to resist "push" than "pull," or its "crushing strength" is much greater than its "tensile" strength. Consequently cast iron, though very suitable for any parts of machinery which have to resist push or "compression," is quite unsuitable for parts which will be subjected to pull or "tension."

The weight which is required to crush a short bar of cast iron of one square inch in sectional area is somewhere about 48 tons, while a pull of 8 tons is sufficient to break a similar bar.

Owing to the weakness of cast iron under tension, and the fact that it is incapable of "elongation," but gives way suddenly when the strain becomes too great, it is an unsuitable material for any part which will be subjected to a bending force, when the one side of the part is subjected to a crushing strain, while the other side is in tension.

Where cast iron is used for beams and such like, if the beam be of H section, as is usually the case, the H being set on its side so that the beam really consists of two parallel bars or "flanges" of cast iron united by a web, then we see that usually the lower flange is made very much stronger than is the upper one, to allow for the difference between the tensile and compressive strengths of the iron, the upper flange being in compression, while the lower one is in tension.

In spite of these objections, cast iron is still the material most used for the manufacture of a large proportion of the parts of an engine, and in engineering work generally, on account of its cheapness and stiffness, and the ease with which castings, even of intricate shapes, can be made from it.

WROUGHT IRON

This cast iron contains a large amount of carbon, which makes it very fluid and easy to run into the moulds; but owing to this carbon, it cannot be "worked" at a red heat—that is, if we hammer it, instead of yielding in the place hit by the hammer, and so taking a new shape (as would damp clay or lead), it crumbles to pieces.

In order to make the cast iron "workable," it must be turned into wrought iron by removing the carbon.

To do this, when it is in a molten state air is forced through it in a furnace, the molten mass continually being stirred or "puddled," when the carbon in the cast iron combines with the oxygen in the air, passing off as a gas, leaving behind the pure iron only.

As a matter of fact this iron is by no means "pure," there being many impurities mixed up with it, the chief of these being "slag" (which is a fusible glassy mixture, used to protect the iron from the action of the air during puddling).

To remove this slag, the newly-formed wrought iron is taken from the furnace while still white hot and in a pasty state, and is passed between powerful iron rollers driven by machinery, or else hammered under a steam hammer, when the slag is squeezed out of it much in the same way as the butter-milk is squeezed out of the butter or the water out of a wet cloth. The wrought iron is now in a fit state to be forged into any desired shape, and, if necessary, more pieces of wrought iron can be welded on to this piece.

If the iron is to be made into rails or angle iron or bars or plates, it is taken from these first "rolls," and while still red hot is passed through other sets of rolls, each of which draws the iron out longer and longer, and nearer and nearer to the desired shape, until the last pair of rolls, the surfaces of which have been made of the shapes of the two sides of whatever section is required, finish the operation, the rough and shapeless lump of wrought iron which was taken out of the puddling furnace being in the space of a few seconds converted into long lengths of rails or angle irons, or what not, each true to gauge, any part of any one of which being exactly like any part of another. Where plates are to be made, the rolls are of course flat, or rather, true cylindrical, and the lump of iron is passed backward and forward through the same pair, which are gradually brought closer and closer together on each successive passage of the iron until the desired thinness is reached, the iron never having been reheated during the process, and never really having been taken out of the rolls.

When the spongy lumps of newly-made wrought iron have been removed from the furnace and the slag squeezed out in the rolls or under the steam hammer, the rough blocks of clean iron are known as "blooms." These blooms are not of any very great size; so if a large forging is to be made, a number of these blooms are heated to a welding heat and brought together, and by means of the steam hammer are welded into one solid mass of the desired size, from which a crank shaft or any other forging can be made.

Wrought iron is a very tough and strong material, which, in addition to being easily forged at a red heat, can be bent when cold to a considerable extent without fracturing. Also, it is very ductile, that is, it can be "drawn down" into very thin wire by dragging it through tapered holes in a steel plate, each hole being slightly smaller than the last, until the desired degree of fineness is reached.

It will not stand so great a crushing strain as will cast iron, giving way under a load of about 17 tons to the square inch, as against the 48 tons required to crush the cast iron pillar of 1 square inch in sectional area. On the other hand, it will stand a much greater tensile strain—namely, 22 tons to the square inch, against the

8 tons for cast iron. Also, when subjected to a tensile strain, it does not give way suddenly when the limit of its strength is reached, as does cast iron, but elongates to a considerable extent before actually giving way.

Generally, wrought iron is a very reliable material, not subject to sudden fracture from unknown causes as is cast iron, and, under proper treatment, is relatively as strong in the thin parts as in the thick, there being no loss of strength where the thin part joins on to the thick.

The chief objections to its use are that, owing to its having to be forged into shape, intricate pieces are most difficult to make, and hollows inside a forging are almost impossible. Also, though its tensile strength is much greater than that of cast iron, it falls considerably short in the matter of strength when under compression.

STEEL

Between wrought iron and cast iron comes steel, in that it contains a certain proportion of carbon, though not nearly so much as does cast iron.

It has most of the good points of both these materials, beside many possessed by neither.

It is found that by adding a certain amount of carbon, varying from 0·1 to 1·5 per cent., to the pure iron, the strength of the material, which is now called steel, is greatly increased, both as regards tension and compression.

There are many processes by which steel is made, some by removing a part of the carbon from cast iron, others by adding carbon to wrought iron, but all having the same general result.

If the percentage of carbon in the steel be relatively large, it can still be cast, as can cast iron, but with difficulty, not being nearly so "fluid" as the cast iron. Also, it is extremely subject to blow-holes, which often render the casting useless. The higher this percentage of carbon the more easily can the steel be cast and the less the liability to blow-holes; but such steel is extremely hard and brittle, and very difficult to "work," and owing to its lack of "toughness" is of but little use in the manufacture of machinery.

So, generally, cast steel is made with a lower percentage of carbon when it is less hard and brittle.

When we see tools marked "cast steel," the steel is obtained by first raising bars of wrought iron imbedded in charcoal to a high temperature, and keeping them at this temperature for a considerable time, when the wrought iron takes up sufficient carbon from the fuel to turn it into steel.

This steel is then broken up into small pieces and melted in a "crucible," after which it is poured into a cast-iron mould which has been previously heated, and on being removed from the mould, which is generally of rectangular or octagonal shape, the "ingot," as it is called, is carefully reheated and then forged into bars ready for making the tools, when it is known as "cast steel" or "tool steel."

When the tool has been made into the required shape, it is first "hardened" by suddenly cooling it by plunging, when at a red heat, into water or oil, which makes it extremely hard, but also very brittle. After hardening, the tool is first ground on a grindstone or emery wheel into the exact shape required, and then is again heated to a certain point, this reheating being called "tempering," when it becomes less hard but also very much less brittle, and is now ready for final grinding and sharpening on an oil-stone. According to the amount of this reheating or tempering, so the hardness and brittleness of the steel vary.

We know that the blades of a pocket-knife sometimes snap off and sometimes bend. If they snap (supposing the steel originally to have been good), it means that the tempering after hardening was not carried far enough, while if they bend, it was carried too far, making the steel soft and "malleable." The "hard" blade (which snapped) could be made very sharp, though the edge soon broke away, while the "soft" blade could not be sharpened at all well, the edge "turning" and refusing to cut.

If this hardened or tempered steel be again brought to a red heat and allowed to cool very slowly by burying it in ashes or lime, it is "annealed" or made comparatively soft, when it can be filed or cut in a machine.

This sort of steel is not suitable for engineering work generally, partly on account of the difficulty of working it, whether hot under the hammer, or when annealed, with file and chisel, but also because, though immensely strong both under tension and compression, it is not very reliable on account of its brittleness and its liability to break under sharp and repeated blows.

In the making of engines, boilers, and nearly all ordinary engineering work, a much softer kind of steel known as "mild steel," containing considerably less carbon, is used.

This mild steel is exceedingly malleable and ductile, it works well and easily when at a red heat, and also can be bent and twisted into almost any shape when cold. It can be welded, though with difficulty, and is generally most reliable. It cannot be hardened or tempered as can cast steel, but it does not need such careful annealing after being heated. Sound and reliable castings are now being made by several processes, of mild steel ; but all these processes are still more or less expensive, which prevents the general substitution of mild-steel castings for the cast-iron ones which are so easily made.

The tensile strength of mild steel averages about 28 tons to the square inch, as against the 8 tons for cast iron, and the 22 tons for wrought iron. Its strength under crushing strain is much greater than that of wrought iron, but is not so great as for cast.

For almost all purposes in engineering mild steel is rapidly taking the place of wrought iron ; for the plating of hulls of ships it is especially valuable, as, on account of its great strength and toughness, much thinner and lighter plates can be used.

Next in importance to the engineer, after iron and steel, come copper, tin, and zinc.

COPPER

Copper in the metallic state is found in several parts of the world, but not to any great extent in the British Isles, where most of the metal is obtained from its ores.

There are many different sorts of copper ore, the metallic copper combining with many other metals and minerals, so it is impossible to give any general idea of the processes by which the metal can be obtained from the ore as could be done in the case of iron, the processes varying so greatly with the different sorts of ore. When the metallic copper has been obtained it is cast into "ingots," which are then rolled into sheets, or drawn into wire, the metal being extremely ductile.

By itself, copper is not of very much use in engineering, except for making steam and other pipes, for which it is peculiarly suitable, by reason of its being readily worked "cold," which allows of the pipes being conveniently bent to the required shapes.

It does not make good castings, nor can it be welded. It is one of the best conductors of heat, and so is used to a certain extent for the fire boxes of locomotives, to allow the heat of the fire to pass freely through it to the water in the boiler. It is very largely used in all electrical work in the shape of wire, being also an excellent conductor of electricity.

Where two pieces of copper have to be joined together, or flanges fixed on to the ends of a pipe, it is done by "brazing," an "alloy" (or mixture of certain metals) called "spelter" being melted into the joint, the parts to be joined by the spelter being raised to a red heat, the surfaces of the metal being meanwhile kept from the action of the air (which would oxidise them and prevent the spelter from adhering) by what is known as a "flux," the usual flux being borax, which melts and forms a sort of glaze over the copper, under which the melted spelter works itself, making a very strong joint.

When copper is being worked cold it requires annealing from time to time; unlike steel, which is annealed by bringing to a red heat and cooling very slowly, copper is annealed by "quenching," when red hot, in water, when it again becomes soft and workable. If this annealing be not done often enough, the copper becomes hard after much hammering, and finally splits, thus spoiling the work.

Pieces of copper can also be joined together by "soldering," which is somewhat the same as brazing, except that the solder melts at a very much lower temperature than does the spelter, which is convenient, but it makes by no means a strong joint.

Copper has its greatest value to the engineer when melted together with tin and zinc to form alloys, known generally by the name of "brass."

The copper in itself is too soft to be of much use, and does not work well with the file or in the machine, but the addition of a certain proportion of either tin or zinc, or both, gives a resulting alloy much harder and stronger than either of the original metals, easily cast, and working well with the file or in the machine.

GUN METAL OR BRONZE

The particular sort of "brass" which is most used in good engineering work is "gun metal" or "bronze."

This alloy contains copper, tin, and zinc, in proportions varying, for different purposes, between the following limits:—

Copper . .	80 to 88 per cent.
Tin . . .	9 to 12 ,,
Zinc . . .	2 to 5 ,,

Generally, as the proportion of tin is increased, so the gun metal becomes harder and more brittle.

Gun metal melts at a much lower temperature than does cast iron, and being very fluid when melted, runs freely into the moulds, giving good, sound, and strong castings, little liable to blow-holes, and much tougher than cast iron, and consequently better able to stand shocks and jars.

Iron, we saw, somewhat rapidly "corrodes" in the presence of air and moisture, combining with the oxygen of the air to form an oxide. Gun metal, however, remains practically unaffected by air and water, which, in addition to its great reliability, makes it peculiarly suitable for the manufacture of cocks and valves and the parts of pumps which are exposed to the action of the water.

These considerations also make it the most suitable material for screw propellers and their fittings.

Owing to its great first cost, gun metal is not generally used for large castings. For cylinders and such like, cast iron really is more suitable on account of its stiffness, and the fact that its harder surface stands the wear and tear due to the working back and forth of the piston and slide valve better than would gun metal.

The working parts of bearings, such as plummer blocks, thrust blocks, and main bearings, are usually made of gun metal, as also are crank and cross-head brasses, as it is found that the friction between gun metal and iron or steel, provided the bearing surfaces are properly lubricated, is slight; and owing to the gun metal being the softer, the bearing, which is easily renewed, wears away instead of the "journal" or bearing surface of the crank shaft or pin, which cannot well be renewed.

In making gun metal from the copper, tin, and zinc, the copper, which requires the greatest heat to melt it, is first melted down in a crucible in the furnace; then the tin is put in, the molten copper supplying the necessary heat for melting it, the alloy remaining fluid, though at a considerably lower temperature than was required to melt the copper when alone. Finally the zinc is added, the mixture being thoroughly stirred during the operation. The temperature of the mass has again fallen, but notwithstanding this, it still remains quite fluid, the melting point of copper being 1,950 degrees Fahrenheit, while that of gun metal is only 1,830 degrees.

Generally, in foundries, instead of making all new metal from the copper, tin, and zinc, old worn-out castings and pieces of machinery and the turnings and borings from the machine shop, are remelted and cast into ingots, to get rid of some of the dirt and impurities, and to render the metal more uniform in its composition. These ingots are then used for the making of the castings.

BRASS

Brass, properly so called, contains no tin, being an alloy of copper and zinc in the proportions of about 67 per cent. of copper to 33 per cent. of zinc. It is considerably softer than gun metal, and so is not much used for castings for engines. If the proportion of copper be slightly increased, to say 68 or 70 per cent., the brass becomes very malleable and ductile, and can be drawn into wire or "solid drawn" tubes, in which form it is much used for the tubes of condensers and such like purposes.

MUNTZ METAL

Muntz metal, another form of brass, contains about 60 per cent. of copper to 40 per cent. of zinc, to which 1 per cent. of lead is added, to make it still more malleable.

It can be forged while hot, or rolled into sheets and bars, and having considerable tensile strength, is much used for making bolts and rods for pumps.

There is one serious objection to the use of Muntz metal for work in salt water, for when the bolts are in contact with copper or gun metal in such positions, galvanic action takes place, the zinc in the Muntz metal being eaten away, leaving only the copper.

NAVAL BRASS

It has been found that this galvanic action is prevented by the addition of a little tin to the Muntz metal, so an alloy of copper, 62 per cent., zinc, 37 per cent., tin, 1 per cent., is generally used instead of Muntz metal for naval work, the other properties of the two alloys being practically the same. This alloy is known as "naval brass."

TIN

Tin is not used by itself in engineering work. Even the so-called tin plate is not really tin, but is sheet iron or steel coated with tin to preserve it from the action of air and moisture. The sheet iron, after being thoroughly cleaned, so as to have a real metallic surface, is rubbed over with sal-ammoniac to act as a flux, and then dipped in a bath of molten tin, when a certain amount of the tin sticks to the surface of the iron, forming a coating practically impervious to air or moisture.

The chief use of tin, however, as we have seen, is in the making of alloys with copper.

ZINC

By itself this metal is only used, in engineering work, for the purpose of protecting iron or steel surfaces from the effects of galvanic action. Thus, inside boilers "slabs" of zinc are suspended in "metallic contact" with the iron of the boiler, and when galvanic action takes place, as it often does, the zinc is eaten away while the boiler itself does not suffer. Zinc is also used for protecting the surfaces of steel and iron somewhat in the same way as is tin, but its good effects are more lasting.

Articles thus coated with zinc are called "galvanised." Zinc is extensively used, as we have seen, in the making of alloys with copper.

LEAD

Lead is not used at all by itself in engines, except for "counterbalance weights," when its high "specific gravity" is valuable. It is, however, used to some extent in certain alloys.

ANTI-FRICTION METALS

It is found that where two metal surfaces work against each other, under pressure, even though properly lubricated, much better results are obtained, as regards friction, where the materials of which these surfaces are made, are suitable.

As one of these surfaces, such as crank pin or cross-head pin, is almost invariably of wrought iron or steel, we need only consider the other bearing surface.

A wrought-iron or steel bearing surface is the worst possible, there being a great tendency for the two parts to "seize" together, when both journal and bearing are ruined.

Cast iron makes a very much better bearing surface than does wrought iron, and is used to a considerable extent for the plummer blocks of cheap machinery.

Gun metal again is much better than cast iron, and is the material most commonly used for the purpose, especially in small work. On account of the high first cost of gun metal plummer blocks and the "bodies" of bearings generally are made of cast iron, with a pair of "brasses," as they are called, fitted in the cast iron for the journal to work on.

Better still than gun metal are the various special alloys known generally as "white metal." This white metal is very soft, and would not be strong enough to stand the strain alone, so brasses are used with a comparatively thin layer of white metal on the inside to form the bearing surface.

The white metal is kept in place in the brass and prevented from being squeezed out by "fillets" made in the brass itself, the fillets, however, not actually touching the journal.

Formerly white metal was only used in main bearings and plummer blocks, but now it is also being used for crank-head brasses, cross-head brasses, and for lining the face of the guide slipper, where it rubs against the guide; also the faces of the thrust collars in the thrust block are made of white metal.

The composition of the different kinds of white metal varies considerably, but generally they contain the following metals—tin, copper, antimony, lead, with, in some sorts, zinc and iron as well.

In an engine, these materials are used as follows :—

Cast iron or *cast steel* for practically all the fixed parts, which are not generally subjected to shock and jar as are the moving parts; also for slide valves and the eccentric sheaves. These parts are usually of such complicated shape as to render the use of forged material impossible. Owing to the difficulty of obtaining really sound steel castings, it is more usual to make the cylinders of cast iron, inside which is very generally fitted (in large work) a "cylinder liner" of forged steel or hard close-grained cast iron, which forms the actual working "barrel."

Pistons are now almost invariably made of cast steel, as owing to the simplicity of their shape there is a reasonable probability of obtaining a sound casting. Even if the first casting should prove a failure or "waster," the cost of making a new mould would not be great.

Wrought iron and *mild steel* are used for all moving parts except the pistons and slide valves, these parts being generally subject to alternate tension and compression, excepting the shafting which acts by torsion, for which cast materials are not suitable.

Copper is used for pipes, whether for steam or water, though mild steel is now being largely used for main and auxiliary steam pipes on account of the high pressures of steam generally employed, the necessary strength being obtained on much less weight.

Gun metal is used for all cocks and valves and cylinder and slide case fittings on account of the strength and reliability of the castings, and on account of the metal not being dangerously affected by the sudden alterations in temperature as is cast iron. For pumps, on account of its being practically unaffected by the action of the water, and for propellers and all under-water fittings for the same reason.

It is also used for all brasses on account of its being a suitable material for bearing surfaces, working well with wrought iron or steel.

White metal is used for "lining" the brasses and for the bearing surfaces of the guide slippers, on account of its being the best material known to stand the friction, and also the "knocking" or "hammering" resulting from the sudden changes in direction of motion due to the reciprocating action of the piston.

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